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*Complete Collection of all Questions asked in last 34 years' in **NEET & CBSE AIPMT***

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Arihant Prakashan (Series), Meerut

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PREFACE

Whenever a student decides to prepare for any examination his/her first and foremost curiosity is to know about the type of questions that are expected in the exam. This becomes more important in the context of competitive entrance examinations where there is neck-to-neck competition.

We feel great pleasure in presenting before you this book containing Error Free Chapterwise Topicwise Solutions of **CBSE AIPMT/NEET Physics** Questions from the years 1988 to 2021.

It has been our efforts to provide correct solutions to the best of our knowledge and opinion. Detailed explanatory discussions follow the answers. Discussions are not just sketchy–rather, have been drafted in a manner that the students will surely be able to answer some other related questions too ! Going through this book, the students would be able to have the complete idea of the questions being asked in the test.

We hope this chapterwise solved papers would be highly beneficial to the students. We would be grateful if any discrepancies or mistakes in the questions or answers are brought to our notice so that these could be rectified in subsequent editions.

Publisher

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SYLLABUS

CLASS 11th

UNIT I Physical World and Measurement

Physics Scope and excitement, nature of physical laws Physics, technology and society.

Need for measurement Units of measurement, systems of units, SI units, fundamental and derived units. Length, mass and time measurements, accuracy and precision of measuring instruments, errors in measurement, significant figures. Dimensions of physical quantities, dimensional analysis and its applications.

UNIT II Kinematics

Frame of reference, Motion in a straight line, Position-time graph, speed and velocity. Uniform and non-uniform motion, average speed and instantaneous velocity. Uniformly accelerated motion, velocity-time and position-time graphs, for uniformly accelerated motion (graphical treatment). Elementary concepts of differentiation and integration for describing motion. Scalar and vector quantities: Position and displacement vectors, general vectors, general vectors and notation, equality of vectors, multiplication of vectors by a real number, addition and subtraction of vectors. Relative velocity. Unit vectors. Resolution of a vector in a plane-rectangular components. Scalar and Vector products of Vectors. Motion in a plane. Cases of uniform velocity and uniform acceleration- projectile motion. Uniform circular motion.

UNIT III Laws of Motion

Intuitive concept of force. Inertia, Newton's first law of motion; momentum and Newton's second law of motion, impulse, Newton's third law of motion. Law of conservation of linear momentum and its applications. Equilibrium of concurrent forces. Static and Kinetic friction, laws of friction, rolling friction, lubrication. Dynamics of uniform circular motion. Centripetal force, examples of circular motion (vehicle on level circular road, vehicle on banked road).

UNIT IV Work, Energy and Power

Work done by a constant force and variable force, kinetic energy, work-energy theorem, power. Notion of potential energy, potential energy of a spring, conservative forces, conservation of mechanical energy (kinetic and potential energies), non-conservative forces, motion in a vertical circle, elastic and inelastic collisions in one and two dimensions.

UNIT V Motion of System of Particles and Rigid Body

Centre of mass of a two-particle system, momentum conservation and centre of mass motion. Centre of mass of a rigid body, centre of mass of uniform rod. Moment of a force, torque, angular momentum, conservation of angular momentum with some examples. Equilibrium of rigid bodies, rigid body rotation and equation of rotational motion, comparison of linear and rotational motions, moment of inertia, radius of gyration. Values of MI for simple geometrical objects (no derivation). Statement of parallel and perpendicular axes theorems and their applications.

UNIT VI Gravitation

Kepler's laws of planetary motion. The universal law of gravitation.Acceleration due to gravity and its variation with altitude and depth. Gravitational potential energy, gravitational potential. Escape velocity, orbital velocity of a satellite. Geostationary satellites.

UNIT VII Properties of Bulk Matter

Elastic behavior, Stress-strain relationship. Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, poisson's ratio; elastic energy. Viscosity, Stokes' law, terminal velocity, Reynold's number, streamline and turbulent flow. Critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure, application of surface tension ideas to drops, bubbles and capillary rise. Heat, temperature, thermal expansion, thermal expansion of solids, liquids and gases. Anomalous expansion. Specific heat capacity, C_p, C_v- calorimetry; change of state – latent heat. Heat transfer- conduction and thermal conductivity, convection and radiation. Qualitative ideas of Black Body Radiation, Wein's displacement law and Green House effect. Newton's law of cooling and Stefan's law.

UNIT VIII Thermodynamics

Thermal equilibrium and definition of temperature (zeroth law of Thermodynamics). Heat, work and internal energy. First law of thermodynamics Isothermal and adiabatic processes. Second law of the thermodynamics Reversible and irreversible processes. Heat engines and refrigerators.

UNIT IX Behaviour of Perfect Gas and Kinetic Theory

Equation of state of a perfect gas, work done on compressing a gas. Kinetic theory of gases Assumptions, concept of pressure. Kinetic energy and temperature, degrees of freedom, law of equipartition of energy (statement only) and application to specific heat capacities of gases, concept of mean free path.

UNIT X Oscillations and Waves

Periodic motion-period, frequency, displacement as a function of time. Periodic functions. Simple harmonic motion(SHM) and its equation, phase, oscillations of a spring-restoring force and force constant, energy in SHM–kinetic and potential energies, simple pendulum-derivation of expression for its time period, free, forced and damped oscillations (qualitative ideas only), resonance. Wave motion. Longitudinal and transverse waves, speed of wave motion. Displacement relation for a progressive wave. Principle of superposition of waves, reflection of waves, standing waves in strings and organ pipes, fundamental mode and harmonics. Beats, Doppler effect.

CLASS 12th

UNIT I Electrostatics

Electric charges and their conservation. Coulomb's law-force between two point charges, forces between multiple charges, superposition principle and continuous charge distribution. Electric field, electric field due to a point charge, electric field lines, electric dipole, electric field due to a dipole, torque on a dipole in a uniform electric field. Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges, equipotential surfaces, electrical potential energy of a system of two point charges and of electric diploes in an electrostatic field. Conductors and insulators, free charges and bound charges inside a conductor, Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor, Van de Graaff generator.

UNIT II Current Electricity

Electric current, flow of electric charges in a metallic conductor, drift velocity and mobility and their relation with electric current, Ohm's law, electrical resistance,
V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity. Carbon resistors, colour code for carbon resistors, series and parallel combinations of resistors, temperature dependence of resistance.

Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel. Kirchhoff's laws and simple applications. Wheatstone bridge, metre bridge. Potentiometer-principle and applications to measure potential difference, and for comparing emf of two cells, measurement of internal resistance of a cell.

UNIT III Magnetic Effects of Current and Magnetism

Concept of magnetic field, Oersted's experiment. Biot-Savart's law and its application to current carrying circular loop. Ampere's law and its applications to infinitely long straight wire, straight and toroidal solenoids. Force on a moving charge in uniform magnetic and electric fields. Cyclotron. Force on a current-carrying conductor in a uniform magnetic field. Force between two parallel current-carrying conductors-definition of ampere. Torque experienced by a current loop in a magnetic field, moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter. Current loop as a magnetic dipole and its magnetic dipole moment.

Magnetic dipole moment of a revolving electron. Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field, bar magnet as an equivalent solenoid, magnetic field lines, Earth's magnetic field and magnetic elements. Para-, dia-and ferro-magnetic substances with examples. Electromagnetic and factors affecting their strengths. Permanent magnets.

UNIT IV Electromagnetic Induction and Alternating Currents

Electromagnetic induction Faraday's law, induced emf and current, Lenz's Law, Eddy currents. Self and mutual inductance. Alternating currents, peak and rms value of alternating current/ voltage, reactance and impedance, LC oscillations (qualitative treatment only), LCR series circuit, resonance, power in AC circuits, wattles current. AC generator and transformer.

UNIT V Electromagnetic Waves

Need for displacement current. Electromagnetic waves and their characteristics (qualitative ideas only). Transverse nature of electromagnetic waves. Electromagnetic spectrum (radiowaves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

UNIT VI Optics

Reflection of light, spherical mirrors, mirror formula. Refraction of light, total internal reflection and its applications optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens-maker's formula. Magnification, power of a lens, combination of thin lenses in contact combination of a lens and a mirror. Refraction and dispersion of light through a prism. Scattering of light- blue colour of the sky and reddish appearance of the sun at sunrise and sunset.

Optical instruments Human eye, image formation and accommodation, correction of eye defects (myopia and hypermetropia) using lenses. Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers. Wave optics: Wavefront and Huygens' principle, reflection and refraction of plane wave at a plane surface using wavefronts. Proof of laws of reflection and refraction using Huygens' principle. Interference, Young's double hole experiment and expression for fringe width, coherent sources and sustained interference of light. Diffraction due to a single slit, width of central maximum. Resolving power of microscopes and astronomical telescopes. Polarisation, plane polarised light, Brewster's law, uses of plane polarised light and Polaroids.

UNIT VII Dual Nature of Matter and Radiation

Photoelectric effect, Hertz and Lenard's observations, Einstein's photoelectric equation- particle nature of light. Matter waves- wave nature of particles, de-Broglie relation. Davisson-Germer experiment (experimental details should be omitted, only conclusion should be explained).

UNIT VIII Atoms and Nuclei

Alpha- particle scattering experiments, Rutherford's model of atom, Bohr model, energy levels, hydrogen spectrum. Composition and size of nucleus, atomic masses, isotopes, isobars, isotones. Radioactivity- a, b and g particles/ rays and their properties decay law. Mass-energy relation, mass defect, binding energy per nucleon and its variation with mass number, nuclear fission and fusion.

UNIT IX Electronic Devices

Energy bands in solids (qualitative ideas only), conductors, insulators and semiconductors, semiconductor diode- I-V characteristics in forward and reverse bias, diode as a rectifier,
I-V characteristics of LED, photodiode, solar cell and Zener diode, Zener diode as a voltage regulator. Junction transistor, transistor action, characteristics of a transistor, transistor as an amplifier (common emitter configuration) and oscillator. Logic gates (OR, AND, NOT, NAND and NOR). Transistor as a switch.

01

Units and Measurements

TOPIC 1
Units

01 The angle of 1′ (minute of arc) in radian is nearly equal to **[NEET (Oct.) 2020]**

(a) 2.91×10^{-4} rad (b) 4.85×10^{-4} rad
(c) 4.80×10^{-6} rad (d) 1.75×10^{-2} rad

Ans. *(a)*

$1\text{ minute} = \frac{1}{60}\text{ degree} = \frac{1}{60}\times\frac{\pi}{180}\text{ rad}$
$= 2.91\times10^{-4}\text{ rad}$

02 The unit of thermal conductivity is : **[NEET (National) 2019]**

(a) $J\,m^{-1}\,K^{-1}$
(b) $W\,m\,K^{-1}$
(c) $W\,m^{-1}\,K^{-1}$
(d) $J\,m\,K^{-1}$

Ans. *(c)*

The rate of heat flow through a conductor of length L and area of cross-section A is given by

$$\frac{dQ}{dt} = KA\frac{\Delta T}{L}\text{ J/s or watt}$$

where, K = coefficient of thermal conductivity and

ΔT = change in temperature

$$\Rightarrow \quad K = \frac{L}{A\Delta T}\frac{dQ}{dt}$$

$$\therefore \text{Unit of } K = \frac{\text{metre}}{(\text{metre})^2\times\text{kelvin}}\times\text{watt}$$
$$= Wm^{-1}K^{-1}$$

03 The unit of permittivity of free space, ε_0 is **[CBSE AIPMT 2004]**

(a) coulomb/newton-metre
(b) newton - metre^2 / coulomb^2
(c) coulomb^2 /newton -metre^2
(d) coulomb^2 / (newton - metre)^2

Ans. *(c)*

According to Coulomb's law, the electrostatic force

$$F = \frac{1}{4\pi\varepsilon_0}\times\frac{q_1q_2}{r^2}$$

q_1 and q_2 = charges, r = distance between charges

and ε_0 = permittivity of free space

$$\Rightarrow \quad \varepsilon_0 = \frac{1}{4\pi}\times\frac{q_1q_2}{r^2F}$$

Substituting the units for q, r and F, we obtain unit of ε_0

$$= \frac{\text{coulomb}\times\text{coulomb}}{\text{newton-(metre)}^2}$$
$$= \frac{(\text{coulomb})^2}{\text{newton-(metre)}^2}$$

04 The value of Planck's constant in SI unit is **[CBSE AIPMT 2002]**

(a) 6.63×10^{-31} J-s
(b) 6.63×10^{-30} kg - m / s
(c) 6.63×10^{-32} kg - m^2
(d) 6.63×10^{-34} J - s

Ans. *(d)*

The value of Planck's constant is 6.63×10^{-34} and J-s is unit of the Planck's constant.

05 In a particular system, the unit of length, mass and time are chosen to be 10 cm, 10 g and 0.1 s respectively. The unit of force in this system will be equivalent to **[CBSE AIPMT 1994]**

(a) 0.1 N (b) 1 N (c) 10 N (d) 100 N

Ans. *(a)*

Force $F = [MLT^{-2}]$
$= (10\text{ g})(10\text{ cm})(0.1\text{ s})^{-2}$

Changing these units into MKS system

$F = (10^{-2}\text{ kg})(10^{-1}\text{ m})(10^{-1}\text{ s})^{-2}$
$= 10^{-1}\text{ N} = 0.1\text{ N}$

TOPIC 2
Errors in Measurement and Significant Figure

06 A screw gauge gives the following readings when used to measure the diameter of a wire
Main scale reading : 0 mm
Circular scale reading : 52 divisions
Given that, 1 mm on main scale corresponds to 100 divisions on the circular scale. The diameter of the wire from the above data is **[NEET 2021]**

(a) 0.52 cm
(b) 0.026 cm
(c) 0.26 cm
(d) 0.052 cm

Ans. *(d)*

Given, the main scale reading, MSR = 0

The circular scale reading, CSR = 52 divisions

Now, we shall determine the least count of the screw gauge,

$$\text{LC} = \frac{p}{n}$$

Here, p is the pitch of the screw,

n is the number of circular divisions in one complete revolution.

$$\text{LC} = \frac{1}{100}\text{ mm}$$

$\Rightarrow$ LC = 0.01 mm

$\Rightarrow$ LC = 0.001 cm

Thus, the least count of the screw gauge is 0.001 cm.

Therefore, diameter of the wire of screw gauge,

$D = \text{MSR} + (\text{CSR}\times\text{LC})$

$\Rightarrow \quad D = 0 + (52\times0.001)$

$\Rightarrow \quad D = 0.052$ cm

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07 Time intervals measured by a clock give the following readings
1.25 s, 1.24 s, 1.27 s, 1.21 s and 1.28 s.
What is the percentage relative error of the observations?
[NEET (Oct.) 2020]
(a) 2% (b) 4% (c) 16% (d) 1.6%

Ans. *(d)*
Mean time interval

$$\bar{T} = \frac{1.25 + 1.24 + 1.27 + 1.21 + 1.28}{5}$$

$$\Rightarrow \quad = \frac{6.25}{5} = 1.25 \text{ s}$$

Mean absolute error,

$$\Delta\bar{T} = \frac{|\Delta T_1| + |\Delta T_2| + |\Delta T_3| + |\Delta T_4| + |\Delta T_5|}{5}$$

$$\Rightarrow = \frac{|1.25 - 1.25| + |1.25 - 1.24| + |1.25 - 1.27| + |1.25 - 1.21| + |1.25 - 1.28|}{5}$$

$$\Rightarrow = \frac{0 + 0.01 + 0.02 + 0.04 + 0.03}{5}$$

$$= \frac{0.1}{5} = 0.02 \text{ s}$$

$$\therefore \text{Percentage relative error} = \frac{\Delta\bar{T}}{T} \times 100$$

$$= \frac{0.02}{1.25} \times 100 = 1.6\%$$

08 A screw gauge has least count of 0.01 mm and there are 50 divisions in its circular scale.
The pitch of the screw gauge is
[NEET (Sep.) 2020]
(a) 0.25 mm (b) 0.5 mm
(c) 1.0 mm (d) 0.01 mm

Ans. *(b)*
Given, least count = 0.01 mm
Number of divisions on circular scale = 50
Pitch of the screw gauge = least count × number of divisions on circular scale
$= 0.01 \times 50 = 0.5$ mm
Hence, correct option is (b).

09 Taking into account of the significant figures, what is the value of 9.99 m – 0.0099 m?
[NEET (Sep.) 2020]
(a) 9.98 m (b) 9.980 m
(c) 9.9 m (d) 9.9801 m

Ans. *(a)*
The difference between 9.99 m and 0.0099 m is
$= 9.99 - 0.0099 = 9.9801$ m
Taking significant figures into account, as both the values has two significant figures after decimal.
So, their difference will also have two significant figures after decimal, i.e. 9.98 m.
Hence, correct option is (a).

10 The main scale of a vernier calliper has n divisions/cm. n divisions of the vernier scale coincide with $(n-1)$ divisions of main scale. The least count of the vernier callipers is **[NEET (Odisha) 2019]**
(a) $\frac{1}{(n+1)(n-1)}$ cm (b) $\frac{1}{n}$ cm
(c) $\frac{1}{n^2}$ cm (d) $\frac{1}{n(n+1)}$ cm

Ans. *(c)*
As it is given that n divisions of vernier scale coincide with $(n-1)$ divisions of main scale i.e.

$$n(VSD) = (n-1)MSD$$

$$\Rightarrow \quad 1VSD = \frac{(n-1)}{n} MSD \quad \ldots(i)$$

The least count is the difference between one main scale division (MSD) and one vernier scale division (VSD).

$$\therefore \text{Least Count } (LC) = 1MSD - 1VSD$$

$$= 1MSD - \frac{(n-1)}{n} MSD \text{ [From Eq. (i)]}$$

$$= \left(1 - \frac{(n-1)}{n}\right) MSD = \frac{1}{n} MSD$$

Here, $1MSD = \frac{1}{n}$ cm

$$\Rightarrow \quad LC = \frac{1}{n} \times \frac{1}{n} \text{ cm} = \frac{1}{n^2} \text{ cm}$$

11 A student measured the diameter of a small steel ball using a screw gauge of least count 0.001 cm. The main scale reading is 5 mm and zero of circular scale division coincides with 25 divisions above the reference level. If screw gauge has a zero error of –0.004 cm, the correct diameter of the ball is **[NEET 2018]**
(a) 0.053 cm (b) 0.525 cm
(c) 0.521 cm (d) 0.529 cm

Ans. *(d)*
Given, least count of screw gauge, LC = 0.001 cm
Main scale reading,
MSR = 5 mm = 0.5 cm
Number of coinciding divisions on the circular scale, i.e. Vernier scale reading, VSR = 25
Here, zero error = –0.004 cm
Final reading obtained from the screw gauge is given as
= MSR + VSR × LC – zero error
Final reading from the screw gauge
$= 0.5 + 25 \times 0.001 - (-0.004)$
$= 0.5 + 0.025 + 0.004$
$= 0.5 + 0.029$
$= 0.529$ cm
Thus, the diameter of the ball is 0.529 cm.

12 In an experiment, four quantities a, b, c and d are measured with percentage error 1%, 2%, 3% and 4% respectively. Quantity P is calculated $P = \frac{a^3 b^2}{cd}$%. Error in P is
[NEET 2013]
(a) 14% (b) 10%
(c) 7% (d) 4%

Ans. *(a)*
As given, $P = \frac{a^3 b^2}{cd}$

$$\therefore \quad \frac{\Delta P}{P} \times 100$$

$$= \left(\frac{3\Delta a}{a} + \frac{2\Delta b}{b} + \frac{\Delta c}{c} + \frac{\Delta d}{d}\right) \times 100$$

$$= 3\frac{\Delta a}{a} \times 100 + 2\frac{\Delta b}{b} \times 100 + \frac{\Delta c}{c} \times 100 + \frac{\Delta d}{d} \times 100$$

$= 3 \times 1 + 2 \times 2 + 3 + 4$
$= 3 + 4 + 3 + 4 = 14\%$

13 If the error in the measurement of radius of a sphere is 2%, then the error in the determination of volume of the sphere will be
[CBSE AIPMT 2008]
(a) 4% (b) 6%
(c) 8% (d) 2%

Ans. *(b)*
Volume of a sphere, $V = \frac{4}{3}\pi r^3$

$$\therefore \quad \frac{\Delta V}{V} \times 100 = \frac{3 \times \Delta r}{r} \times 100$$

Here $\frac{\Delta r}{r} \times 100 = 2\%$

$$\therefore \quad \frac{\Delta V}{V} \times 100 = 3 \times 2\% = 6\%$$

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14 The density of a cube is measured by measuring its mass and length of its sides. If the maximum error in the measurement of mass and length are 4% and 3% respectively, the maximum error in the measurement of density will be **[CBSE AIPMT 1996]**

(a) 7% (b) 9%
(c) 12% (d) 13%

Ans. *(d)*

As density $\rho = \frac{m}{V} = \frac{m}{l^3}$

$\therefore \frac{\Delta\rho}{\rho} \times 100 = \pm\left(\frac{\Delta m}{m} + 3\frac{\Delta l}{l}\right) \times 100\%$

$= \pm (4 + 3 \times 3) = \pm 13\%$

15 The percentage errors in the measurement of mass and speed are 2% and 3% respectively. The error in kinetic energy obtained by measuring mass and speed, will be **[CBSE AIPMT 1995]**

(a) 12% (b) 10%
(c) 8% (d) 2%

Ans. *(c)*

Kinetic energy $K = \frac{1}{2}mv^2$

$\therefore \quad \frac{\Delta K}{K} \times 100 = \frac{\Delta m}{m} \times 100 + 2 \times \frac{\Delta v}{v} \times 100$

Here, $\frac{\Delta m}{m} \times 100 = 2\%$

$\Rightarrow \quad \frac{\Delta v}{v} \times 100 = 3\%$

$\therefore \quad \frac{\Delta K}{K} \times 100 = 2\% + 2 \times 3\% = 8\%$

16 In a vernier callipers N divisions of vernier scale coincide with $N-1$ divisions of main scale (in which length of one division is 1 mm). The least count of the instrument should be **[CBSE AIPMT 1994]**

(a) N (b) $N-1$
(c) $\frac{1}{10N}$ (d) $\frac{1}{(N-1)}$

Ans. *(c)*

As given N VSD $= (N-1)$ MSD

VSD = Vernier scale division

MSD = Main scale division

$1\,\text{VSD} = \left(\frac{N-1}{N}\right)\text{MSD}$

LC = least count = 1 MSD − 1 VSD

$$\text{LC} = \left(1 - \frac{N-1}{N}\right)\text{MSD}$$

$$= \frac{1}{N}\text{MSD} = \frac{0.1}{N}\text{ cm} = \frac{1}{10N}\text{ cm}$$

17 A certain body weighs 22.42 g and has a measured volume of 4.7 cc. The possible error in the measurement of mass and volume are 0.01 g and 0.1 cc. Then, maximum error in the density will be **[CBSE AIPMT 1991]**

(a) 22% (b) 2% (c) 0.2% (d) 0.02%

Ans. *(b)*

$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$

$\rho = \frac{m}{V}$

$\therefore \quad \frac{\Delta\rho}{\rho} = \frac{\Delta m}{m} + \frac{\Delta V}{V}$

Here, $\Delta m = 0.01, m = 22.42$

$\Delta V = 0.1, V = 4.7$

$\therefore \quad \frac{\Delta\rho}{\rho} = \left(\frac{0.01}{22.42} + \frac{0.1}{4.7}\right) \times 100 = 2\%$

TOPIC 3
Dimensions

18 If force $[F]$, acceleration $[a]$ and time $[T]$ are chosen as the fundamental physical quantities. Find the dimensions of energy. **[NEET 2021]**

(a) $[F][a][T]$ (b) $[F][a][T^2]$
(c) $[F][a][T^{-1}]$ (d) $[F][a^{-1}][T]$

Ans. *(b)*

Given, fundamental physical quantities are force $[F]$, acceleration $[a]$ and time $[T]$.

Now, we shall determine the dimensions of the energy.

Energy depends on force, acceleration and time as,

$$[E] = [F]^a[a]^b[T]^c$$

$\Rightarrow \quad [ML^2T^{-2}] = [MLT^{-2}]^a[LT^{-2}]^b[T]^c$

$\Rightarrow \quad [ML^2T^{-2}] = [M]^a[L]^{a+b}[T]^{-2a-2b+c}$

Comparing the powers of M, L and T on both sides, we get

$a = 1, a + b = 2$

and $-2a - 2b + c = -2$

$\Rightarrow \quad 1 + b = 2 \Rightarrow \quad b = 1,$

$\Rightarrow \quad -2(1) - 2(1) + c = -2 \quad \Rightarrow \quad c = 2$

The dimensions of the energy are $[F^1][a]^1[T]^2$.

19 If E and G respectively denote energy and gravitational constant. then $\frac{E}{G}$ has the dimensions of **[NEET 2021]**

(a) $[M^2][L^{-1}][T^0]$ (b) $[M][L^{-1}][T^{-1}]$
(c) $[M][L^0][T^0]$ (d) $[M^2][L^{-2}][T^{-1}]$

Ans. *(a)*

The dimensions of energy

$[E] = [F] \cdot [d]$

$\Rightarrow \quad [E] = [MLT^{-2}][L] \quad \Rightarrow \quad [E] = [ML^2T^{-2}]$

As we know that, the expression of gravitational force,

$F = \frac{GM_1M_2}{r^2} \quad \Rightarrow \quad G = \frac{Fr^2}{M_1M_2}$

$\therefore \quad [G] = \frac{[F][r^2]}{[M_1][M_2]} \quad \Rightarrow \quad [G] = \frac{[MLT^{-2}][L]^2}{[M][M]}$

$\Rightarrow [G] = [M^{-1}L^3T^{-2}]$

The dimensions of

$\frac{E}{G} = \frac{[ML^2T^{-2}]}{[M^{-1}L^3T^{-2}]} \quad \Rightarrow \quad \left[\frac{E}{G}\right] = [M^2L^{-1}T^0]$

20 Dimensions of stress are **[NEET (Sep.) 2020]**

(a) $[ML^2T^{-2}]$ (b) $[ML^0T^{-2}]$
(c) $[ML^{-1}T^{-2}]$ (d) $[MLT^{-2}]$

Ans. *(c)*

$\because \text{Stress} = \frac{\text{Force}}{\text{Area}}$

$\therefore \text{Dimensions of stress} = \frac{[MLT^{-2}]}{[L^2]}$

$= [ML^{-1}T^{-2}]$

Hence, correct option is (c).

21 A physical quantity of the dimensions of length that can be formed out of c, G and $\frac{e^2}{4\pi\varepsilon_0}$ is [c is velocity of light, G is universal constant of gravitation and e is charge] **[NEET 2017]**

(a) $\frac{1}{c^2}\left[G\frac{e^2}{4\pi\varepsilon_0}\right]^{1/2}$ (b) $c^2\left[G\frac{e^2}{4\pi\varepsilon_0}\right]^{1/2}$

(c) $\frac{1}{c^2}\left[\frac{e^2}{G\,4\pi\varepsilon_0}\right]^{1/2}$ (d) $\frac{1}{c}G\frac{e^2}{4\pi\varepsilon_0}$

Ans. *(a)*

As force $F = \frac{e^2}{4\pi\varepsilon_0 r^2} \quad \Rightarrow \quad \frac{e^2}{4\pi\varepsilon_0} = r^2 \cdot F$

Putting dimensions of r and F, we get,

$\Rightarrow \quad \left[\frac{e^2}{4\pi\varepsilon_0}\right] = [ML^3T^{-2}] \qquad \ldots(i)$

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Also, force, $F = \frac{Gm^2}{r^2}$

$\Rightarrow \quad [G] = \frac{[MLT^{-2}][L^2]}{[M^2]}$

$\Rightarrow \quad [G] = [M^{-1}L^3T^{-2}]$ ...(ii)

and $\left[\frac{1}{c^2}\right] = \frac{1}{[L^2T^{-2}]} = [L^{-2}T^2]$ ...(iii)

Now, checking optionwise,

$$= \frac{1}{c^2}\left(\frac{Ge^2}{4\pi\varepsilon_0}\right)^{1/2} = [L^{-2}T^2][L^6T^{-4}]^{1/2} = [L]$$

22 If energy (E), velocity (v) and time (T) are chosen as the fundamental quantities, the dimensional formula of surface tension will be **[CBSE AIPMT 2015]**

(a) $[Ev^{-2}T^{-1}]$ (b) $[Ev^{-1}T^{-2}]$
(c) $[Ev^{-2}T^{-2}]$ (d) $[E^{-2}v^{-1}T^{-3}]$

Ans. *(c)*

We know that

Surface tension $(S) = \frac{\text{Force}\,[F]}{\text{Length}\,[L]}$

So, $[S] = \frac{[MLT^{-2}]}{[L]} = [ML^0T^{-2}]$

Energy (E) = Force × displacement

$\Rightarrow \quad [E] = [ML^2T^{-2}]$

Velocity $(v) = \frac{\text{displacement}}{\text{time}}$

$\Rightarrow \quad [v] = [LT^{-1}]$

As, $S \propto E^a v^b T^c$

where, a, b, c are constants.

From the principle of homogeneity,

$[LHS] = [RHS]$

$\Rightarrow \quad [ML^0T^{-2}] = [ML^2T^{-2}]^a[LT^{-1}]^b[T]^c$

$\Rightarrow \quad [ML^0T^{-2}] = [M^aL^{2a+b}T^{-2a-b+c}]$

Equating the power on both sides, we get

$a = 1, 2a + b = 0, b = -2$

$\Rightarrow \quad -2a - b + c = -2$

$\Rightarrow \quad c = (2a + b) - 2 = 0 - 2 = -2$

So $[S] = [Ev^{-2}T^{-2}] = [Ev^{-2}T^{-2}]$

23 If dimensions of critical velocity v_c of a liquid flowing through a tube are expressed as $[\eta^x\rho^y r^z]$, where η, ρ and r are the coefficient of viscosity of liquid, density of liquid and radius of the tube respectively, then the values of x, y and z are given by **[CBSE AIPMT 2015]**

(a) 1, – 1, – 1 (b) – 1, – 1, 1
(c) – 1, – 1, – 1 (d) 1, 1, 1

Ans. *(a)*

Key Concept According to principle of homogeneity of dimension states that, a physical quantity equation will be dimensionally correct, if the dimensions of all the terms occurring on both sides of the equations are same.

Given critical velocity of liquid flowing through a tube are expressed as

$$v_c \propto \eta^n\rho^y r^z$$

Coefficient of viscosity of liquid,

$$\eta = [ML^{-1}T^{-1}]$$

Density of liquid, $\rho = [ML^{-3}]$

Radius of a tube $r = [L]$

Critical velocity of liquid $v_c = [ML^0T^{-1}]$

$\Rightarrow [M^0L^1T^{-1}] = [ML^{-1}T^{-1}]^x[ML^{-3}]^y[L]^z$

$[M^0L^1T^{-1}] = [M^{x+y}L^{-x-3y+z}T^{-x}]$

Comparing exponents of M, L and L, we get

$x + y = 0, -x - 3y + z = 1, -x = -1$

$\Rightarrow \quad z = -1, x = 1, y = -1$

24 If force (F), velocity (v) and time (T) are taken as fundamental units, then the dimensions of mass are **[CBSE AIPMT 2014]**

(a) $[FvT^{-1}]$ (b) $[FvT^{-2}]$
(c) $[Fv^{-1}T^{-1}]$ (d) $[Fv^{-1}T]$

Ans. *(d)*

We know that

$F = ma$

$\Rightarrow \quad F = \frac{mv}{t} \quad \Rightarrow \quad m = \frac{Ft}{v}$

$[M] = \frac{[F][T]}{[v]} = [Fv^{-1}T]$

25 The dimensions of $(\mu_0\varepsilon_0)^{-1/2}$ are **[CBSE AIPMT 2012]**

(a) $[L^{1/2}T^{-1/2}]$ (b) $[L^{-1}T]$
(c) $[LT^{-1}]$ (d) $[L^{1/2}T^{1/2}]$

Ans. *(c)*

$(\mu_0\varepsilon_0)^{-1/2}$ is the expression for velocity of light.

As $c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$

So, dimension of $c = [LT^{-1}]$

26 The dimensions of $\frac{1}{2}\varepsilon_0 E^2$, where ε_0 is permittivity of free space and E is electric field, are **[CBSE AIPMT 2010]**

(a) $[ML^2T^{-2}]$ (b) $[ML^{-1}T^{-2}]$
(c) $[ML^2T^{-1}]$ (d) $[MLT^{-1}]$

Ans. *(b)*

As we know that,

Dimension of $\varepsilon_0 = [M^{-1}L^{-3}T^4A^2]$

Dimension of $E = [MLT^{-3}A^{-1}]$

So, dimension of

$$\frac{1}{2}\varepsilon_0 E^2 = [M^{-1}L^{-3}T^4A^2] \times [MLT^{-3}A^{-1}]^2$$

$$= [ML^{-1}T^{-2}]$$

27 If the dimensions of a physical quantity are given by $[M^aL^bT^c]$, then the physical quantity will be **[CBSE AIPMT 2009]**

(a) pressure if $a = 1, b = -1, c = -2$
(b) velocity if $a = 1, b = 0, c = -1$
(c) acceleration if $a = 1, b = 1, c = -2$
(d) force if $a = 0, b = -1, c = -2$

Ans. *(a)*

(i) Dimensions of velocity $= [M^0L^1T^{-1}]$
Here, $a = 0, b = 1, c = -1$

(ii) Dimensions of acceleration $= [M^0L^1T^{-2}]$
Here, $a = 0, b = 1, c = -2$

(iii) Dimensions of force $= [M^1L^1T^{-2}]$
Here, $a = 1, b = 1, T = -2$

(iv) Dimensions of pressure $= [M^1L^{-1}T^{-2}]$
$\therefore$ Here, $a = 1, b = -1, c = -2$
$\therefore$ The physical quantity is pressure.

28 Which two of the following five physical parameters have the same dimensions? **[CBSE AIPMT 2008]**

(i) Energy density
(ii) Refractive index
(iii) Dielectric constant
(iv) Young's modulus
(v) Magnetic field

(a) (ii) and (iv) (b) (iii) and (v)
(c) (i) and (iv) (d) (i) and (v)

Ans. *(c)*

Energy density $= \frac{\text{Energy}}{\text{Volume}} \Rightarrow u = \frac{E}{V}$

Dimensions of $u = \frac{\text{Dimensions of } E}{\text{Dimensions of } V}$

$$= \frac{[ML^2T^{-2}]}{[L^3]} = [ML^{-1}T^{-2}]$$

Refractive index is a dimensionless quantity. Dielectric constant is a dimensionless quantity.

Young's modulus

$$= \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{F/A}{\Delta l/l} = [ML^{-1}T^{-2}]$$

Magnetic field $= \frac{\text{Force}}{\text{Charge} \times \text{Velocity}} = \frac{F}{qv}$

$$= \frac{[MLT^{-2}]}{[AT][LT^{-1}]} = [MT^{-2}A^{-1}]$$

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29 Dimensions of resistance in an electrical circuit, in terms of dimension of mass M, of length L, of time T and of current I, would be **[CBSE AIPMT 2007]**

(a) $[ML^2T^{-3}I^{-1}]$ (b) $[ML^2T^{-2}]$
(c) $[ML^2T^{-1}I^{-1}]$ (d) $[ML^2T^{-3}I^{-2}]$

Ans. *(d)*

According to Ohm's law, $V \propto I$

and $V = IR$

$$\text{Resistance, } R = \frac{\text{Potential difference}}{\text{Current}} = \frac{V}{i} = \frac{W}{qi}$$

$\left(\because \text{Potential difference is equal to the work done per unit charge}\right)$

So, dimensions of R

$$= \frac{\text{Dimensions of work}}{\text{Dimensions of charge}} \times \text{Dimensions of current}$$

$$= \frac{[ML^2T^{-2}]}{[IT][I]} = [ML^2T^{-3}I^{-2}]$$

30 The velocity v of a particle at time t is given by $v = at + \frac{b}{t+c}$, where a, b and c are constants. The dimensions of a, b and c are respectively **[CBSE AIPMT 2006]**

(a) $[LT^{-2}]$, $[L]$ and $[T]$
(b) $[L^2]$, $[T]$ and $[LT^2]$
(c) $[LT^2]$, $[LT]$ and $[L]$
(d) $[L]$, $[LT]$ and $[T^2]$

Ans. *(a)*

The given expression is

$$v = at + \frac{b}{t+c}$$

From principle of homogeneity

$$[a][t] = [v]$$

$$[a] = \frac{[v]}{[t]} = \frac{[LT^{-1}]}{[T]} = [LT^{-2}]$$

Similarly, $[c] = [t] = [T]$

Further, $\frac{[b]}{[t+c]} = [v]$

or $[b] = [v][t+c]$

or $[b] = [LT^{-1}][T] = [L]$

31 The ratio of the dimensions of Planck's constant and that of the moment of inertia is the dimension of **[CBSE AIPMT 2005]**

(a) frequency
(b) velocity
(c) angular momentum
(d) time

Ans. *(a)*

Energy carried by photon is given by

$$E = h\nu$$

$$\Rightarrow \quad h = \text{Planck's constant} = \frac{E}{\nu}$$

$$\therefore \quad [h] = \frac{[ML^2T^{-2}]}{[T^{-1}]} = [ML^2T^{-1}]$$

and I = moment of inertia $= MR^2$

$$\Rightarrow \quad [I] = [ML^2]$$

$$\text{Hence, } \frac{[h]}{[I]} = \frac{[ML^2T^{-1}]}{[ML^2]} = [T^{-1}]$$

$$= \frac{1}{[T]} = \text{dimension of frequency}$$

Alternative

$$\frac{h}{I} = \frac{E/\nu}{I}$$

$$= \frac{E \times T}{I} = \frac{(\text{kg-m}^2/\text{s}^2) \times \text{s}}{(\text{kg-m}^2)}$$

$$= \frac{1}{\text{s}} = \frac{1}{\text{time}} = \text{frequency}$$

Thus, dimensions of $\frac{h}{I}$ is same as that of frequency.

32 The dimensions of universal gravitational constant are **[CBSE AIPMT 2004, 1992]**

(a) $[M^{-1}L^3T^{-2}]$ (b) $[ML^2T^{-1}]$
(c) $[M^{-2}L^3T^{-2}]$ (d) $[M^{-2}L^2T^{-1}]$

Ans. *(a)*

According to Newton's law of gravitation, the force of attraction between two masses m_1 and m_2 separated by a distance r is,

$$F = \frac{G\, m_1 m_2}{r^2} \Rightarrow G = \frac{Fr^2}{m_1 m_2}$$

Substituting the dimensions for the quantities on the right hand side, we obtain

$$\text{Dimensions of } G = \frac{[MLT^{-2}][L^2]}{[M]^2} = [M^{-1}L^3T^{-2}]$$

33 Planck's constant has the dimensions of **[CBSE AIPMT 2001]**

(a) linear momentum
(b) angular momentum
(c) energy
(d) power

Ans. *(b)*

$$E = h\nu$$

$$\Rightarrow h = \text{Planck's constant} = \frac{\text{Energy } (E)}{\text{frequency } (\nu)}$$

$$\therefore [h] = \frac{E}{\nu} = \frac{[ML^2T^{-2}]}{[T^{-1}]} = [ML^2T^{-1}]$$

(a) Linear momentum = Mass × velocity
or $p = m \times v = [M][LT^{-1}] = [MLT^{-1}]$

(b) Angular momentum
= Moment of inertia × angular velocity
or $L = I \times \omega = mr^2\omega$ $[\because I = mr^2]$
$\therefore \quad [L] = [M][L^2][T^{-1}] = [ML^2T^{-1}]$

(c) Energy $[E] = [ML^2T^{-2}]$

(d) Power = Force × velocity
or $P = F \times v$
$\therefore \quad [P] = [MLT^{-2}][LT^{-1}] = [ML^2T^{-3}]$

Hence, option (b) is correct.

34 A pair of physical quantities having same dimensional formula is **[CBSE AIPMT 2000]**

(a) force and torque
(b) work and energy
(c) force and impulse
(d) linear momentum and angular momentum

Ans. *(b)*

(a) Force = Mass × acceleration
or $F = ma$
$= [M][LT^{-2}] = [MLT^{-2}]$

Torque = Moment of inertia × angular acceleration
or $\tau = I \times \alpha = [ML^2][T^{-2}] = [ML^2T^{-2}]$

(b) Work = Force × displacement
or $W = F \times d = [MLT^{-2}][L] = [ML^2T^{-2}]$

$$\text{Energy} = \frac{1}{2} \times \text{mass} \times (\text{velocity})^2$$

or $K = \frac{1}{2}mv^2 = [M][LT^{-1}]^2 = [ML^2T^{-2}]$

(c) Force as discussed above
$[F] = [MLT^{-2}]$

Impulse = Force × time-interval
$\therefore \quad [I] = [MLT^{-2}][T] = [MLT^{-1}]$

(d) Linear momentum = Mass × velocity
or $p = mv$
$\therefore \quad [p] = [M][LT^{-1}] = [MLT^{-1}]$

Angular momentum = Moment of inertia × angular velocity
or $[L] = [I] \times [\omega]$
$\therefore \quad [L] = [ML^2][T^{-1}] = [ML^2T^{-1}]$

Hence, we observe that choice (b) is correct.

35 The dimensional formula for magnetic flux is **[CBSE AIPMT 1999]**

(a) $[ML^2T^{-2}A^{-1}]$ (b) $[ML^3T^{-2}A^{-2}]$
(c) $[M^0L^{-2}T^2A^{-2}]$ (d) $[ML^2T^{-1}A^2]$

Ans. *(a)*

Mathematically, magnetic flux

$$\phi = BA \qquad \ldots(i)$$

but magnetic force

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$F = BiI$ or $B = \frac{F}{iI}$

Putting the value of B in Eq. (i), we have

$$\phi = \frac{F}{iI} A$$

Thus, dimensions of $\phi = \frac{[MLT^{-2}][L^2]}{[AL]}$

$= [ML^2T^{-2}A^{-1}]$

36 The force F on a sphere of radius r moving in a medium with velocity v is given by $F = 6\pi\eta rv$. The dimensions of η are

[CBSE AIPMT 1997]

(a) $[ML^{-3}]$ (b) $[MLT^{-2}]$
(c) $[MT^{-1}]$ (d) $[ML^{-1}T^{-1}]$

Ans. *(d)*

Viscous force on a sphere of radius r is

$$F = 6\pi\eta rv \Rightarrow \eta = \frac{F}{6\pi rv}$$

$$[\eta] = \frac{[F]}{[r][v]} = \frac{[MLT^{-2}]}{[L][LT^{-1}]} = [ML^{-1}T^{-1}]$$

37 Which of the following will have the dimensions of time ?

[CBSE AIPMT 1996]

(a) LC (b) $\frac{R}{L}$ (c) $\frac{L}{R}$ (d) $\frac{C}{L}$

Ans. *(c)*

$\frac{L}{R}$ is time constant of R-L circuit so, dimensions of $\frac{L}{R}$ is same as that of time.

Alternative

$$\frac{\text{Dimensions of } L}{\text{Dimensions of } R} = \frac{[ML^2T^{-2}A^{-2}]}{[ML^2T^{-3}A^{-2}]} = [T]$$

38 An equation is given as $\left(p + \frac{a}{V^2}\right) = b\frac{\theta}{V}$, where p = pressure, V = volume and θ = absolute temperature. If a and b are constants, then dimensions of a will be

[CBSE AIPMT 1996]

(a) $[ML^5T^{-2}]$ (b) $[M^{-1}L^5T^2]$
(c) $[ML^{-5}T^{-1}]$ (d) $[ML^5T]$

Ans. *(a)*

From principle of homogeneity of dimensions.

Dimensions of p = dimensions of $\frac{a}{V^2}$

$$p = \frac{a}{V^2} \Rightarrow a = pV^2$$

$$= [ML^{-1}T^{-2}][L^3]^2 = [ML^5T^{-2}]$$

39 Which of the following is a dimensional constant ?

[CBSE AIPMT 1995]

(a) Refractive index
(b) Poisson's ratio
(c) Relative density
(d) Gravitational constant

Ans. *(d)*

A quantity which has dimensions and also has a constant value is called dimensional constant.
Here, gravitational constant (G) is a dimensional constant.

40 Turpentine oil is flowing through a tube of length l and radius r. The pressure difference between the two ends of the tube is p. The viscosity of oil is given by

$$\eta = \frac{p(r^2 - x^2)}{4vl}$$

where, v is the velocity of oil at distance x from the axis of the tube. The dimensions of η are

[CBSE AIPMT 1993]

(a) $[M^0L^0T^0]$ (b) $[MLT^{-1}]$
(c) $[ML^2T^{-2}]$ (d) $[ML^{-1}T^{-1}]$

Ans. *(d)*

Pressure

$$(p) = \frac{\text{Force}}{\text{Area}} = \frac{[MLT^{-2}]}{[L^2]} = [ML^{-1}T^{-2}]$$

Velocity, $v = [LT^{-1}]$

From principle of homogeneity, the dimensions of r^2 and x^2 are same.

So, the dimensions of viscosity,

$$\eta = \frac{[ML^{-1}T^{-2}][L^2]}{[LT^{-1}][L]} = [ML^{-1}T^{-1}]$$

41 The time dependence of physical quantity p is given by $p = p_0 \exp(-\alpha t^2)$, where α is a constant and t is the time. The constant α

[CBSE AIPMT 1992]

(a) is dimensionless
(b) has dimensions $[T^{-2}]$
(c) has dimensions $[T^2]$
(d) has dimensions of p

Ans. *(b)*

$p = p_0 \exp(-\alpha t^2)$

As powers of exponential quantity is dimensionless, so αt^2 is dimensionless.

or αt^2 = dimensionless $= [M^0L^0T^0]$

$\therefore \quad \alpha = \frac{1}{t^2} = \frac{1}{[T^2]} = [T^{-2}]$

42 If p represents radiation pressure, c represents speed of light and S represents radiation energy striking unit area per sec. The non-zero integers x, y, z such that $p^x S^y c^z$ is dimensionless are

[CBSE AIPMT 1992]

(a) $x = 1, y = 1, z = 1$
(b) $x = -1, y = 1, z = 1$
(c) $x = 1, y = -1, z = 1$
(d) $x = 1, y = 1, z = -1$

Ans. *(c)*

Radiation pressure, $p = [ML^{-1}T^{-2}]$

Velocity of light, $c = [LT^{-1}]$

Energy striking unit area per second

$$S = \frac{[ML^2T^{-2}]}{[L^2T]} = [MT^{-3}]$$

Now, $p^x S^y c^z$ is dimensionless.

$\therefore [M^0L^0T^0] = p^x S^y c^z$

or $[M^0L^0T^0] = [M^1L^{-1}T^{-2}]^x [M^1T^{-3}]^y [L^1T^{-1}]^z$

or $[M^0L^0T^0] = [M]^{x+y} [L]^{-x+z} [T]^{-2x-3y-z}$

From principle of homogeneity of dimensions

$x + y = 0$ ...(i)
$-x + z = 0$ ...(ii)
$-2x - 3y - z = 0$ ...(iii)

Solving Eqs. (i), (ii) and (iii), we get

$x = 1, \quad y = -1, \quad z = 1$

43 The dimensional formula for permeability of free space, μ_0 is

[CBSE AIPMT 1991]

(a) $[MLT^{-2}A^{-2}]$ (b) $[ML^{-1}T^2A^{-2}]$
(c) $[ML^{-1}T^{-2}A^2]$ (d) $[ML^{-2}A^{-1}]$

Ans. *(a)*

From Biot-Savart law

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

Idl = current element

r = displacement vector

$$\mu_0 = \frac{4\pi r^2 (dB)}{Idl\sin\theta} = \frac{[L^2][MT^{-2}A^{-1}]}{[A][L]}$$

$= [MLT^{-2}A^{-2}]$

44 The frequency of vibration f of a mass m suspended from a spring of spring constant k is given by a relation of the type $f = Cm^x k^y$, where C is a dimensionless constant. The values of x and y are

[CBSE AIPMT 1990]

(a) $x = \frac{1}{2}, y = \frac{1}{2}$ (b) $x = -\frac{1}{2}, y = -\frac{1}{2}$
(c) $x = \frac{1}{2}, y = -\frac{1}{2}$ (d) $x = -\frac{1}{2}, y = \frac{1}{2}$

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Ans. *(d)*

As $f = Cm^x k^y$

$\therefore$ (Dimension of f) $= C$ (dimension of $m)^x$ $\times$ (dimensions of $k)^y$

$[T^{-1}] = C\ [M]^x\ [MT^{-2}]^y$ ...(i)

$\left(\text{where, } k = \dfrac{\text{force}}{\text{length}}\right)$

Applying the principle of homogeneity of dimensions, we get

$x + y = 0,\ -2y = -1$ or $y = \dfrac{1}{2}$

$\therefore \quad x = -\dfrac{1}{2}$

45 According to Newton, the viscous force acting between liquid layers of area A and velocity gradient $\dfrac{\Delta v}{\Delta z}$ is given by $F = -\eta A \dfrac{dv}{dz}$, where η is constant called **[CBSE AIPMT 1990]**

(a) $[ML^{-2}T^{-2}]$

(b) $[M^0L^0T^0]$

(c) $[ML^2T^{-2}]$

(d) $[ML^{-1}T^{-1}]$

Ans. *(d)*

As $F = -\eta A \dfrac{dv}{dz} \Rightarrow \eta = -\dfrac{F}{A\left(\dfrac{dv}{dz}\right)}$

As $F = [MLT^{-2}],\ A = [L^2]$

$dv = [LT^{-1}], dz = [L]$

$\therefore \quad \eta = \dfrac{[MLT^{-2}][L]}{[L^2][LT^{-1}]} = [ML^{-1}T^{-1}]$

46 The dimensional formula of pressure is **[CBSE AIPMT 1990]**

(a) $[MLT^{-2}]$ (b) $[ML^{-1}T^2]$

(c) $[ML^{-1}T^{-2}]$ (d) $[MLT^{-2}]$

Ans. *(c)*

$\text{Pressure} = \dfrac{\text{Force}}{\text{Area}} = \dfrac{F}{A} = \dfrac{[MLT^{-2}]}{[L^2]}$

$= [ML^{-1}T^{-2}]$

47 The dimensional formula of torque is **[CBSE AIPMT 1989]**

(a) $[ML^2T^{-2}]$ (b) $[MLT^{-2}]$

(c) $[ML^{-1}T^{-2}]$ (d) $[ML^{-2}T^{-2}]$

Ans. *(a)*

Torque $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

Dimensions of τ = dimension of $\mathbf{r}$ $\times$ dimension of $\mathbf{F}$

$= [L][MLT^{-2}] = [ML^2T^{-2}]$

48 If $x = at + bt^2$, where x is the distance travelled by the body in kilometer while t is the time in second, then the unit of b is **[CBSE AIPMT 1989]**

(a) km/s (b) km-s (c) km/s^2 (d) km-s^2

Ans. *(c)*

Ans. As $x = at + bt^2$

According to the concept of dimensional analysis and principle of homogeneity

$\therefore$ unit of x = unit of bt^2

$\therefore \quad \text{unit of } b = \dfrac{\text{unit of } x}{\text{unit of } t^2} = \text{km/s}^2$

49 Dimensional formula of self-inductance is **[CBSE AIPMT 1989]**

(a) $[MLT^{-2}A^{-2}]$ (b) $[ML^2T^{-1}A^{-2}]$

(c) $[ML^2T^{-2}A^{-2}]$ (d) $[ML^2T^{-2}A^{-1}]$

Ans. *(c)*

As we know that emf induced in the inductors is given by

$e = L\dfrac{di}{dt} \quad \Rightarrow L = \dfrac{edt}{di} = \dfrac{W}{q} \cdot \dfrac{dt}{di}$

$= \dfrac{[ML^2T^{-2}][T]}{[AT][A]} = [ML^2T^{-2}A^{-2}]$

50 Of the following quantities, which one has dimensions different from the remaining three? **[CBSE AIPMT 1989]**

(a) Energy per unit volume

(b) Force per unit area

(c) Product of voltage and charge per unit volume

(d) Angular momentum

Ans. *(d)*

Dimensions of energy per unit volume

$= \dfrac{\text{Dimensions of energy}}{\text{Dimensions of volume}}$

$= \dfrac{[ML^2T^{-2}]}{[L^3]} = [ML^{-1}T^{-2}]$

Dimensions of force per unit area

$= \dfrac{\text{Dimensions of force}}{\text{Dimensions of area}} = \dfrac{[MLT^{-2}]}{[L^2]}$

$= [ML^{-1}T^{-2}]$

Voltage $\times$ Charge/ Volume

$= \dfrac{\left(\dfrac{W}{q}\right) \times (it)}{l^3} = \dfrac{(W)}{(l^3)} = \dfrac{[ML^2T^{-2}]}{[L^3]}$

$= [ML^{-1}T^{-2}]$

Angular momentum

$= (r)(p) = (r)(mv) = [L][M][LT^{-1}]$

$= [ML^2T^{-1}]$

So, dimensions of angular momentum is different from other three.

51 The dimensional formula for angular momentum is **[CBSE AIPMT 1988]**

(a) $[M^0L^2T^{-2}]$

(b) $[ML^2T^{-1}]$

(c) $[MLT^{-1}]$

(d) $[ML^2T^{-2}]$

Ans. *(b)*

Angular momentum

$L = \mathbf{r} \times \mathbf{p} = \mathbf{r} \times mv$

$\therefore$ Dimensional formula for angular momentum

$= [L][M][LT^{-1}] = [ML^2T^{-1}]$

52 If C and R denote capacitance and resistance respectively, then the dimensional formula of CR is **[CBSE AIPMT 1988]**

(a) $[M^0L^0T]$ (b) $[M^0L^0T^0]$

(c) $[M^0L^0T^{-1}]$

(d) Not expressible in terms of $[MLT]$

Ans. *(a)*

$\because C = \dfrac{q}{V} = \dfrac{q}{\dfrac{W}{q}} = \dfrac{q^2}{W} = \dfrac{(it)^2}{F \cdot x} = \dfrac{[AT]^2}{[ML^2T^{-2}]}$

$= [M^{-1}L^{-2}T^4A^2]$ and $R = \dfrac{V}{i} = \dfrac{W}{qi}$

$= \dfrac{F \cdot x}{i^2 t} = \dfrac{[ML^2T^{-2}]}{[AT][A]} = [ML^2T^{-3}A^{-2}]$

$\therefore$ Dimensional formula of CR

$= [M^{-1}L^{-2}T^4A^2]\,[ML^2T^{-3}A^{-2}] = [M^0L^0T]$

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02

Motion in a Straight Line

TOPIC 1
Terms Related to Motion

01 A person travelling in a straight line moves with a constant velocity v_1 for certain distance 'x' and with a constant velocity v_2 for next equal distance. The average velocity v is given by the relation **[NEET (Odisha) 2019]**

(a) $\frac{1}{v}=\frac{1}{v_1}+\frac{1}{v_2}$ (b) $\frac{2}{v}=\frac{1}{v_1}+\frac{1}{v_2}$

(c) $\frac{v}{2}=\frac{v_1+v_2}{2}$ (d) $v=\sqrt{v_1 v_2}$

Ans. *(b)*

For distance x, the person moves with constant velocity v_1 and for another x distance, he moves with constant velocity of v_2, then

Total distance travelled, $D = x + x = 2x$

Total time-taken, $T = t_1 + t_2$

$$= \frac{x}{v_1}+\frac{x}{v_2} \qquad \left[\because t=\frac{\text{Distance}}{\text{Velocity}}\right]$$

The average velocity,

$$V_{av}=\frac{\text{total distance}}{\text{total time}}=\frac{D}{T}$$

$$v=\frac{2x}{\frac{x}{v_1}+\frac{x}{v_2}}=\frac{2}{\frac{1}{v_1}+\frac{1}{v_2}} \qquad [\because v_{av}=v]$$

$$\Rightarrow \quad \frac{1}{v_1}+\frac{1}{v_2}=\frac{2}{v}$$

02 Preeti reached the metro station and found that the escalator was not working. She walked up the stationary escalator in time t_1. On other days, if she remains stationary on the moving escalator, then the escalator takes her up in time t_2. The time taken by her to walk up on the moving escalator will be **[NEET 2017]**

(a) $\frac{t_1+t_2}{2}$ (b) $\frac{t_1 t_2}{t_2-t_1}$

(c) $\frac{t_1 t_2}{t_2+t_1}$ (d) $t_1 - t_2$

Ans. *(c)*

Speed of walking $=\frac{h}{t_1}=v_1$

Speed of escalator $=\frac{h}{t_2}=v_2$

Time taken when she walks over running escalator

$$\Rightarrow \quad t=\frac{h}{v_1+v_2}$$

$$\Rightarrow \quad \frac{1}{t}=\frac{v_1}{h}+\frac{v_2}{h}=\frac{1}{t_1}+\frac{1}{t_2}$$

$$\Rightarrow \quad t=\frac{t_1 t_2}{t_1+t_2}$$

03 If the velocity of a particle is $v = At + Bt^2$, where A and B are constants, then the distance travelled by it between 1s and 2s is **[NEET 2016]**

(a) $3A + 7B$ (b) $\frac{3}{2}A+\frac{7}{3}B$

(c) $\frac{A}{2}+\frac{B}{3}$ (d) $\frac{3}{2}A + 4B3$

Ans. *(b)*

Velocity of the particle is given as

$$v = At + Bt^2$$

where A and B are constants.

$$\Rightarrow \quad \frac{dx}{dt}=At+Bt^2 \qquad \left[\because v=\frac{dx}{dt}\right]$$

$$\Rightarrow \quad dx=(At+Bt^2)\,dt$$

Integrating both sides, we get

$$\int_{x_1}^{x_2} dx=\int_1^2 (At+Bt^2)\,dt$$

$$\Rightarrow \quad \Delta x = x_2 - x_1 = A\int_1^2 t\,dt + B\int_1^2 t^2 dt$$

$$= A\left[\frac{t^2}{2}\right]_1^2 + B\left[\frac{t^3}{3}\right]_1^2$$

$$= \frac{A}{2}(2^2-1^2)+\frac{B}{3}(2^3-1^3)$$

$\therefore$ Distance travelled between 1s and 2s is

$$\Delta x=\frac{A}{2}\times(3)+\frac{B}{3}(7)=\frac{3A}{2}+\frac{7B}{3}$$

04 Two cars P and Q start from a point at the same time in a straight line and their positions are represented by $X_P(t)=at+bt^2$ and $X_Q(t)=ft-t^2$. At what time do the cars have the same velocity? **[NEET 2016]**

(a) $\frac{a-f}{1+b}$ (b) $\frac{a+f}{2(b-1)}$

(c) $\frac{a+f}{2(1+b)}$ (d) $\frac{f-a}{2(1+b)}$

Ans. *(d)*

Velocity of each car is given by

$$V_P=\frac{dx_P(t)}{dt}=a+2bt$$

and $$V_Q=\frac{dx_Q(t)}{dt}=f-2t$$

It is given that $V_P = V_Q$

$$\Rightarrow \quad a+2bt=f-2t$$

$$\Rightarrow \quad t=\frac{f-a}{2(b+1)}$$

05 A particle of unit mass undergoes one-dimensional motion such that its velocity varies according to $v(x)=\beta x^{-2n}$ where, β and n are constants and x is the position of the particle. The acceleration of

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the particle as a function of x, is given by **[CBSE AIPMT 2015]**

(a) $-2n\beta^2 x^{-2n-1}$ (b) $-2n\beta^2 x^{-4n-1}$
(c) $-2\beta^2 x^{-2n+1}$ (d) $-2n\beta^2 e^{-4n+1}$

Ans. *(b)*

Given, $v = \beta x^{-2n}$

$$a = \frac{dv}{dt} = \frac{dx}{dt}\cdot\frac{dv}{dx}$$

$$\Rightarrow \quad a = v\frac{dv}{dx} = (\beta x^{-2n})(-2n\beta x^{-2n-1})$$

$$\Rightarrow \quad a = -2n\beta^2 x^{-4n-1}$$

06 The motion of a particle along a straight line is described by equation

$$x = 8 + 12t - t^3$$

where, x is in metre and t in sec. The retardation of the particle when its velocity becomes zero, is **[CBSE AIPMT 2012]**

(a) 24 ms^{-2} (b) zero
(c) 6 ms^{-2} (d) 12 ms^{-2}

Ans. *(d)*

Concept Double differentiation of displacement equation gives acceleration and single differentiation gives velocity of the body.

Given, $x = 8 + 12t - t^3$

We know $v = \frac{dx}{dt}$

and acceleration $a = \frac{dv}{dt}$

So, $v = 12 - 3t^2$ and $a = -6t$

At $t = 2$ s

$v = 0$ and $a = -6 \times 2$

$a = -12$ m/s^2

So, retardation of the particle = 12 m/s^2.

07 A body is moving with velocity 30 m/s towards East. After 10s, its velocity becomes 40 m/s towards North. The average acceleration of the body is **[CBSE AIPMT 2011]**

(a) 7 m/s^2 (b) $\sqrt{7}$ m/s^2
(c) 5 m/s^2 (d) 1 m/s^2

Ans. *(c)*

Average acceleration

$$n = \frac{\text{Change in velocity}}{\text{Total time}}$$

$$a = \frac{|\mathbf{v}_f - \mathbf{v}_i|}{\Delta t} = \frac{\sqrt{30^2 + 40^2}}{10}$$

$$= \frac{\sqrt{900 + 1600}}{10} = 5 \text{ ms}^{-2}$$

08 A particle moves a distance x in time t according to the equation $x = (t + 5)^{-1}$. The acceleration of particle is proportional to **[CBSE AIPMT 2010]**

(a) (velocity)$^{3/2}$ (b) (distance)^2
(c) (distance)$^{-2}$ (d) (velocity)$^{2/3}$

Ans. *(a)*

Given, distance $x = (t + 5)^{-1}$ ...(i)

Differentiating Eq. (i) w.r.t. t, we get

$$\frac{dx}{dt} = (v) = \frac{-1}{(t+5)^2} \quad \text{...(ii)}$$

Again, differentiating Eq. (ii) w.r.t. t, we get

$$\frac{d^2x}{dt^2} = (a) = \frac{2}{(t+5)^3} \quad \text{...(iii)}$$

Comparing Eqs. (ii) and (iii), we get

$(a) \propto (v)^{3/2}$

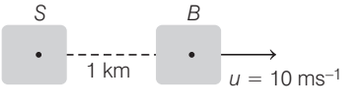
09 A bus is moving with a speed of 10 ms^{-1} on a straight road. A scooterist wishes to overtake the bus in 100 s. If the bus is at a distance of 1 km from the scooterist, with what speed should the scooterist chase the bus? **[CBSE AIPMT 2009]**

(a) 20 ms^{-1} (b) 40 ms^{-1}
(c) 25 ms^{-1} (d) 10 ms^{-1}

Ans. *(a)*

Let v be the relative velocity of scooter (s) w.r.t. bus (B), then

$$v = v_S - v_B$$



$$\therefore \quad v_S = v + v_B \quad \text{...(i)}$$

Relative velocity = Displacement / Time

$$= \frac{1000}{100} = 10 \text{ ms}^{-1}$$

Now, substituting the value of v in Eq. (i), we get

$$v_S = 10 + 10 = 20 \text{ ms}^{-1}$$

10 A particle moving along x-axis has acceleration f, at time t, given by $f = f_0\left(1 - \frac{t}{T}\right)$, where f_0 and T are constants. The particle at $t = 0$ has zero velocity. In the time interval between $t = 0$ and the instant when $f = 0$, the particle's velocity (v_x) is **[CBSE AIPMT 2007]**

(a) $f_0 T$ (b) $\frac{1}{2} f_0 T^2$ (c) $f_0 T^2$ (d) $\frac{1}{2} f_0 T$

Ans. *(d)*

Acceleration

$$f = f_0\left(1 - \frac{t}{T}\right)$$

or $$f = \frac{dv}{dt} = f_0\left(1 - \frac{t}{T}\right) \qquad \left[\because f = \frac{dv}{dt}\right]$$

or $$dv = f_0\left(1 - \frac{t}{T}\right)dt \quad \text{...(i)}$$

Integrating Eq. (i) on both sides,

$$\int dv = \int f_0\left(1 - \frac{t}{T}\right)dt$$

$$\therefore \quad v = f_0 t - \frac{f_0}{T}\cdot\frac{t^2}{2} + c \quad \text{...(ii)}$$

where, c is constant of integration.

Now, when $t = 0$, $v = 0$.

So, from Eq. (ii), we get $c = 0$

$$\therefore \quad v = f_0 t - \frac{f_0}{T}\cdot\frac{t^2}{2} \quad \text{...(iii)}$$

As, $$f = f_0\left(1 - \frac{t}{T}\right)$$

When, $f = 0$,

$$0 = f_0\left(1 - \frac{t}{T}\right)$$

As, $f_0 \neq 0$, so, $1 - \frac{t}{T} = 0$

$$\therefore \quad t = T$$

Substituting, $t = T$ in Eq. (iii), we get

$$v_x = f_0 T - \frac{f_0}{T}\cdot\frac{T^2}{2} = f_0 T - \frac{f_0 T}{2} = \frac{1}{2} f_0 T$$

11 A car moves from X to Y with a uniform speed v_u and returns to X with a uniform speed v_d. The average speed for this round trip is **[CBSE AIPMT 2007]**

(a) $\frac{2v_d v_u}{v_d + v_u}$ (b) $\sqrt{v_u v_d}$
(c) $\frac{v_d v_u}{v_d + v_u}$ (d) $\frac{v_u + v_d}{2}$

Ans. *(a)*

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Time taken}}$$

Let t_1 and t_2 be times taken by the car to go from X to Y and then from Y to X respectively.

Then, $$t_1 + t_2 = \frac{XY}{v_u} + \frac{XY}{v_d}$$

$$= XY\left(\frac{v_u + v_d}{v_u v_d}\right)$$

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Total distance travelled = $XY + XY = 2XY$
Therefore, average speed of the car for this round trip is

$$v_{av} = \frac{2XY}{XY\left(\frac{v_u + v_d}{v_u v_d}\right)} \quad \text{or} \quad v_{av} = \frac{2v_u v_d}{v_u + v_d}$$

12 The position x of a particle w.r.t. time t along x-axis is given by $x = 9t^2 - t^3$, where x is in metre and t in sec. What will be the position of this particle when it achieves maximum speed along the $+x$ direction? **[CBSE AIPMT 2007]**

(a) 32 m (b) 54 m
(c) 81 m (d) 24 m

Ans. *(b)*

Given, the position x of a particle w.r.t. time t along x-axis

$$x = 9t^2 - t^3 \quad ...(i)$$

Differentiating Eq. (i), w.r.t. time, we get speed, i.e.

$$v = \frac{dx}{dt} = \frac{d}{dt}(9t^2 - t^3)$$

or $v = 18t - 3t^2$ ...(ii)

Again differentiating Eq. (ii), with respect to time, we get acceleration, i.e.

$$a = \frac{dv}{dt} = \frac{d}{dt}(18t - 3t^2)$$

or $a = 18 - 6t$ ...(iii)

Now, when speed of particle is maximum, its acceleration is zero, i.e.

$a = 0$

i.e. $18 - 6t = 0$ or $t = 3$ s

Putting in Eq. (i), we obtain position of particle at the time

$$x = 9(3)^2 - (3)^3 = 9(9) - 27$$
$$= 81 - 27 = 54 \text{ m}$$

13 A particle moves along a straight line OX. At a time t (in second), the distance x (in metre) of the particle from O is given by

$$x = 40 + 12t - t^3$$

How long would the particle travel before coming to rest? **[CBSE AIPMT 2006]**

(a) 24 m (b) 40 m (c) 56 m (d) 16 m

Ans. *(c)*

Concept First X by X differentiating displacement equation we get velocity of the body, since body comes to rest so velocity becomes zero. Now by putting the value of time t in displacement equation we get the distance travelled by the body when it comes to rest.

Distance travelled by the particle is

$$x = 40 + 12t - t^3$$

We know that, velocity is the rate of change of distance i.e. $v = \frac{dx}{dt}$.

$$\therefore \quad v = \frac{d}{dt}(40 + 12t - t^3)$$
$$= 0 + 12 - 3t^2$$

but final velocity $v = 0$

$$\therefore \quad 12 - 3t^2 = 0$$

or $t^2 = \frac{12}{3} = 4$

or $t = 2$ s

Hence, distance travelled by the particle before coming to rest is given by

$$x = 40 + 12(2) - (2)^3$$
$$= 40 + 24 - 8$$
$$= 64 - 8 = 56 \text{ m}$$

14. The displacement x of a particle varies with time t as $x = ae^{-\alpha t} + be^{\beta t}$, where a, b, α and β are positive constants. The velocity of the particle will **[CBSE AIPMT 2005]**

(a) decrease with time
(b) be independent of α and β
(c) drop to zero when $\alpha = \beta$
(d) increase with time

Ans. *(d)*

Given, $x = ae^{-\alpha t} + be^{\beta t}$

Velocity $v = \frac{dx}{dt} = -a\alpha e^{-\alpha t} + b\beta e^{\beta t}$

$$= A + B$$

where, $A = -a\alpha e^{-\alpha t}$

$B = b\beta e^{\beta t}$

The value of term $A = -a\alpha e^{-\alpha t}$ decreases and of term $B = b\beta e^{\beta t}$ increases with time. As a result, velocity goes on increasing with time.

15. A particle moves along a straight line such that its displacement at any time t is given by $s = 3t^3 + 7t^2 + 14t + 5$. The acceleration of the particle at $t = 1$ s is **[CBSE AIPMT 2000]**

(a) 18 m/s^2
(b) 32 m/s^2
(c) 29 m/s^2
(d) 24 m/s^2

Ans. *(b)*

Concept On double differentiation of displacement equation gives acceleration of body

i.e. $a = \frac{d^2x}{dt^2}$

The displacement of a particle along a straight line is

$$s = 3t^3 + 7t^2 + 14t + 5 \quad ...(i)$$

Differentiating Eq. (i) w.r.t. time, which gives the velocity

$$v = \frac{ds}{dt} = \frac{d}{dt}(3t^3 + 7t^2 + 14t + 5)$$
$$= \frac{d}{dt}(3t^3) + \frac{d}{dt}(7t^2) + \frac{d}{dt}(14t) + \frac{d}{dt}(5)$$
$$v = 3\frac{d}{dt}(t^3) + 7\frac{d}{dt}(t^2) + 14\frac{d}{dt}(t) + 0 \quad ...(ii)$$

(as differentiation of a constant is zero)

Now use $\frac{d}{dt}(x^n) = nx^{n-1}$

So, $v = 3(3)t^{3-1} + 7(2)(t^{2-1}) + 14(t^{1-1})$

$\Rightarrow$ $v = 9t^2 + 14t + 14$ ....(iii)

$(\because t^0 = 1)$

Again differentiating Eq. (iii) w.r.t. time, which gives the acceleration

$$a = \frac{dv}{dt} = \frac{d}{dt}(9t^2 + 14t + 14)$$
$$= 18t + 14 + 0 = 18t + 14$$

At $t = 1$ s,
$a = 18(1) + 14 = 18 + 14 = 32$ m/s^2

16. The position x of a particle varies with time t, as $x = at^2 - bt^3$. The acceleration of the particle will be zero at time t equals to **[CBSE AIPMT 1997]**

(a) zero (b) $\frac{a}{3b}$
(c) $\frac{2a}{3b}$ (d) $\frac{a}{b}$

Ans. *(b)*

Acceleration, $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$,

Velocity $v = \frac{dx}{dt}$.

The given equation is

$$x = at^2 - bt^3$$

Velocity, $v = \frac{dx}{dt} = 2at - 3bt^2$

Acceleration $a = \frac{dv}{dt} = 2a - 6bt$

but $a = 0$ (given)

$\therefore 2a - 6bt = 0$ or $6bt = 2a$ or $t = \frac{2a}{6b} = \frac{a}{3b}$

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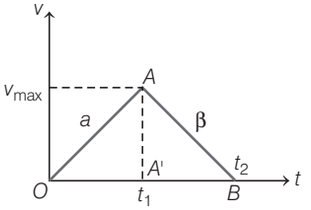
17. A car accelerates from rest at a constant rate α for some time, after which it decelerates at a constant rate β and comes to rest. If the total time elapsed is t, then the maximum velocity acquired by the car is **[CBSE AIPMT 1994]**

(a) $\left(\frac{\alpha^2+\beta^2}{\alpha\beta}\right)t$ (b) $\left(\frac{\alpha^2-\beta^2}{\alpha\beta}\right)t$

(c) $\frac{(\alpha+\beta)\,t}{\alpha\beta}$ (d) $\left(\frac{\alpha\beta\, t}{\alpha+\beta}\right)$

Ans. *(d)*

This situation is plotted on (v-t) graph. In (v-t) graph, OA represents the accelerated part and AB represents the decelerated part.



Let t_1 and t_2 be the times for part OA and AB respectively.

At point A velocity is maximum and let it be v_{max}.

$\therefore \quad v_{max} = \alpha t_1 = \beta t_2$

But $\quad t = t_1 + t_2 = \frac{v_{max}}{\alpha} + \frac{v_{max}}{\beta}$

$$= v_{max}\left(\frac{1}{\alpha}+\frac{1}{\beta}\right) = v_{max}\left(\frac{\alpha+\beta}{\alpha\beta}\right)$$

or $\quad v_{max} = t\left(\frac{\alpha\beta}{\alpha+\beta}\right)$

Alternative

This problem can also be solved by checking the dimensions on both sides. On checking the dimensions we note that the dimensions of option (d) match with that of velocity.

18. A particle moves along a straight line such that its displacement at any time t is given by $s = (t^3 - 6t^2 + 3t + 4)$ m

The velocity when the acceleration is zero, is **[CBSE AIPMT 1994]**

(a) 3 ms^{-1} (b) -12 ms^{-1}

(c) 42 ms^{-1} (d) -9 ms^{-1}

Ans. *(d)*

Given, $s = t^3 - 6t^2 + 3t + 4$

$\therefore$ Velocity $v = \frac{ds}{dt} = 3t^2 - 12t + 3$ ...(i)

Acceleration a is given by

$$a = \frac{dv}{dt}$$

$\therefore \quad a = 6t - 12$ ...(ii)

For $a = 0$, we have $0 = 6t - 12$

or $\quad t = 2$ s

Hence, at $t = 2$ s the velocity will be

$$v = 3\times 2^2 - 12\times 2 + 3 = -9 \text{ ms}^{-1}$$

19. A train of 150 m length is going towards North direction at a speed of 10 m/s. A parrot flies at the speed of 5 m/s towards South direction parallel to the railways track. The time taken by the parrot to cross the train is **[CBSE AIPMT 1992]**

(a) 12 s (b) 8 s (c) 15 s (d) 10 s

Ans. *(d)*

Concept Velocity of A w.r.t. B is given by $v_{AB} = v_A - v_B$.

Relative velocity of the parrot w.r.t. the train

$$= [10 - (-5)] \text{ ms}^{-1} = 15 \text{ ms}^{-1}.$$

Time taken by the parrot to cross the train

$$= \frac{150}{15} = 10 \text{ s}$$

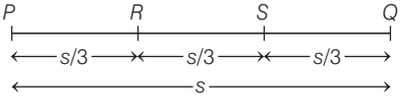
20. A bus travelling the first one-third distance at a speed of 10 km/h, the next one-third at 20 km/h and the last one-third at 60 km/h. The average speed of the bus is **[CBSE AIPMT 1991]**

(a) 9 km/h (b) 16 km/h

(c) 18 km/h (d) 48 km/h

Ans. *(c)*

Concept Average speed can be calculated as the total distance travelled divided by the total time takn.



Let t_1, t_2, t_3 be times taken in covering distances PR, RS and SQ respectively.

$\therefore \quad t_1 = \frac{(s/3)}{10}, \quad t_2 = \frac{(s/3)}{20}$

and $\quad t_3 = \frac{(s/3)}{60}$

$\therefore$ Average speed $= \frac{\text{Total distance}}{\text{Total time}}$

$$= \frac{s}{t_1 + t_2 + t_3}$$

$$= \frac{s}{\frac{(s/3)}{10} + \frac{(s/3)}{20} + \frac{(s/3)}{60}}$$

$$= \frac{s}{(s/18)} = 18 \text{ km/h}$$

21. A car moves a distance of 200 m. It covers the first-half of the distance at speed 40 km/h and the second-half of distance at speed v km / h. The average speed is 48 km/h. Find the value of v. **[CBSE AIPMT 1991]**

(a) 56 km/h (b) 60 km/h

(c) 50 km/h (d) 48 km/h

Ans. *(b)*

Average speed $= \frac{\text{Total distance}}{\text{Total time}}$

Let t_1, t_2 be time taken during first-half and second-half respectively.

So, $\quad t_1 = \frac{100}{40}$ s

and $\quad t_2 = \frac{100}{v}$ s

So, according to average speed formula

$$48 = \frac{200}{\left(\frac{100}{40}\right) + \left(\frac{100}{v}\right)}$$

or $\quad \frac{1}{40} + \frac{1}{v} = \frac{2}{48} = \frac{1}{24}$

or $\quad \frac{1}{v} = \frac{2}{120} = \frac{1}{60}$

$\Rightarrow \quad v = 60$ km/h

22. A car covers the first-half of the distance between two places at 40 km/h and other half at 60 km/h. The average speed of the car is **[CBSE AIPMT 1990]**

(a) 40 km/h (b) 48 km/h

(c) 50 km/h (d) 60 km/h

Ans. *(b)*

Let the distance between two places be d and t_1 is time taken by car to travel first-half length, t_2 is time taken by car to travel second-half length. Time taken by car to travel first-half length,

$$t_1 = \frac{\left(\frac{d}{2}\right)}{40} = \frac{d}{80}$$

Time taken by car to travel second-half length,

$$t_2 = \frac{\left(\frac{d}{2}\right)}{60} = \frac{d}{120}$$

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$\therefore$ Total time $= t_1 + t_2$

$$= \frac{d}{80} + \frac{d}{120}$$

$$= d\left(\frac{1}{80} + \frac{1}{120}\right) = \frac{d}{48}$$

$\therefore$ Average speed

$$= \frac{d}{t_1 + t_2} = \frac{d}{\left(\frac{d}{48}\right)} = 48 \text{ km/h}$$

Alternative

$$v_{av} = \frac{2v_1v_2}{v_1 + v_2} = \frac{2 \times 40 \times 60}{40 + 60} = 48 \text{ km/h}$$

TOPIC 2

Kinematics Equations of Uniformly Accelerated Motion

23. A car starts from rest and accelerates at 5 m/s^2. At $t = 4$s, a ball is dropped out of a window by a person sitting in the car. What is the velocity and acceleration of the ball at $t = 6$ s? (Take, $g = 10 \text{ m/s}^2$) **[NEET 2021]**

(a) 20 m/s, 5 m/s^2
(b) 20 m/s, 0
(c) $20\sqrt{2}$ m/s, 0
(d) $20\sqrt{2}$ m/s, 10 m/s^2

Ans. *(d)*

Given, the initial velocity of a car, $u = 0$

The acceleration of a car, $a = 5 \text{ m/s}^2$

At $t = 4$ s, $v = u + at$

$\Rightarrow$ $v = 0 + (5)4 \Rightarrow v = 20$ m/s

Thus, the final velocity of car at $t = 4$ s is 20 m/s.

At $t = 4$ s, the ball is dropped out of a window by a person sitting in the car.

The velocity of the ball in the x-direction, $v_x = 20 \text{ m/s}$ (due to the car)

Therefore, in the y-direction, the acceleration is equal to the acceleration due to gravity,

$$a_y = g = 10 \text{ m/s}^2$$

The velocity of the ball in the y-direction,

$$v_y = u + a_y t \Rightarrow v_y = 0 + 10 \times 2$$

$\Rightarrow$ $v_y = 20$ m/s

Thus, the velocity of the ball in y-direction is 20 m/s.

The net velocity at $t = 6$s,

$$v = \sqrt{v_x^2 + v_y^2} \Rightarrow v = \sqrt{(20)^2 + (20)^2}$$

$\Rightarrow$ $v = 20\sqrt{2} \text{ m/s}$

Thus, the velocity of the ball at $t = 6$ s is $20\sqrt{2}$ m/s.

and there is no acceleration in the x-direction, $a_x = 0 \text{ ms}^{-2}$

In y-direction, $a_y = 10 \text{ ms}^{-2}$

Now, we shall determine the net acceleration

at $t = 6$ s, $a = \sqrt{a_x^2 + a_y^2}$

$\Rightarrow$ $a = \sqrt{(0) + (10)^2} \Rightarrow a = 10 \text{ ms}^{-2}$

24. A small block slides down on a smooth inclined plane, starting from rest at time $t = 0$. Let s_n be the distance travelled by the block in the interval $t = n - 1$ to $t = n$. Then, the ratio $\frac{s_n}{s_{n+1}}$ is **[NEET 2021]**

(a) $\frac{2n-1}{2n}$ (b) $\frac{2n-1}{2n+1}$ (c) $\frac{2n+1}{2n-1}$ (d) $\frac{2n}{2n-1}$

Ans. *(b)*

Distance covered nth seconds is s_n.

Distance covers in $(n+1)$ th seconds is s_{n+1}.

Initial velocity of small block, $u = 0$

Distance cover in nth seconds,

$$s_n = u + \frac{a}{2}(2n - 1)$$

$$\Rightarrow s_n = 0 + \frac{a}{2}(2n - 1)$$

$$\Rightarrow s_n = \frac{a}{2}(2n - 1) \quad \ldots(i)$$

Distance cover in $(n+1)$th seconds,

$$s_{n+1} = u + \frac{a}{2}[2(n+1) - 1]$$

$$\Rightarrow s_{n+1} = 0 + \frac{a}{2}(2n + 2 - 1)$$

$$\Rightarrow s_{n+1} = \frac{a}{2}(2n + 1) \quad \ldots(ii)$$

On dividing Eq. (i) by Eq. (ii), we get

$$\frac{s_n}{s_{n+1}} = \frac{\frac{a}{2}(2n-1)}{\frac{a}{2}(2n+1)}$$

$$\Rightarrow \frac{s_n}{s_{n+1}} = \frac{(2n-1)}{(2n+1)}$$

25. A person sitting in the ground floor of a building notices through the window of height 1.5 m, a ball dropped from the roof of the building crosses the window in 0.1 s. What is the velocity of the ball when it is at the topmost point of the window? ($g = 10 \text{ m/s}^2$) **[NEET (Oct.) 2020]**

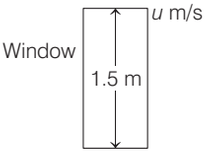
(a) 15.5 m/s (b) 14.5 m/s
(c) 4.5 m/s (d) 20 m/s

Ans. *(b)*

According to question, time taken by the ball to cross the window,

$t = 0.1$ s

$h = 1.5$ m



If u be the velocity at the top most point of the window, then from equation of motion,

$$h = ut + \frac{1}{2}gt^2$$

$$\Rightarrow \quad 1.5 = u \times 0.1 + \frac{1}{2} \times 10 \times (0.1)^2$$

$$\Rightarrow \quad 1.5 = 0.1u + 0.05$$

$$\Rightarrow \quad u = \frac{1.5 - 0.05}{0.1} = \frac{1.45}{0.1} = 14.5 \text{ m/s}$$

26. A ball is thrown vertically downward with a velocity of 20 m/s from the top of a tower. It hits the ground after some time with a velocity of 80 m/s. The height of the tower is ($g = 10 \text{ m/s}^2$) **[NEET (Sep.) 2020]**

(a) 340 m
(b) 320 m
(c) 300 m
(d) 360 m

Ans. *(c)*

Given, $u = 20$ m/s, $v = 80$ m/s and $h = ?$

From kinematic equation of motion,

$$v^2 = u^2 + 2gh$$

$$\Rightarrow \quad h = \frac{v^2 - u^2}{2g}$$

$$= \frac{(80)^2 - (20)^2}{2 \times 10} (\because \text{ given, } g = 10 \text{ m/s}^2)$$

$$= 300 \text{ m}$$

Hence, correct option is (c).

27. A person standing on the floor of an elevator drops a coin. The coin reaches the floor in time t_1 if the elevator is at rest and in time t_2 if the elevator is moving uniformly. The which of the following option is correct? **[NEET (Odisha) 2019]**

(a) $t_1 < t_2$ or $t_1 > t_2$ depending upon whether the lift is going up or down
(b) $t_1 < t_2$
(c) $t_1 > t_2$
(d) $t_1 = t_2$

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Ans. *(d)*

Let h be the height through which the coin is dropped. Then, according to the equation of motion, it is given as

$$h = ut + \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2h}{g}} \quad [\because u = 0]$$

$$\Rightarrow t \propto \frac{1}{\sqrt{g}}$$

As the elevator is moving uniformly i.e. its velocity is constant, so the acceleration is zero.

∴ Relative acceleration of the lift when it is either moving upward or downward is given as, $g' = g \pm a = g \pm 0 = g$

Hence, the time for the coin to reach the floor will remains same i.e. $t_1 = t_2$.

28. A toy car with charge q moves on a frictionless horizontal plane surface under the influence of a uniform electric field **E**. Due to the force q**E**, its velocity increases from 0 to 6 m/s in one second duration. At that instant, the direction of the field is reversed. The car continues to move for two more seconds under the influence of this field. The average velocity and the average speed of the toy car between 0 to 3 seconds are respectively **[NEET 2018]**

(a) 1 m/s, 3.5 m/s
(b) 1 m/s, 3 m/s
(c) 2 m/s, 4 m/s
(d) 1.5 m/s, 3 m/s

Ans. *(b)*

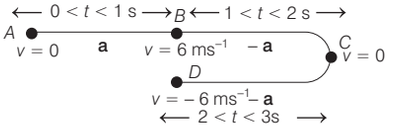
According to the question,

For the time duration $0 < t < 1$ s,

the velocity increase from 0 to 6 ms^{-1}

As the direction of field has been reversed for, $1 < t < 2$ s : the velocity firstly decreases from 6 ms^{-1} to 0.

Then, for $2 < t < 3$ s, as the field strength is same; the magnitude of acceleration would be same, but velocity increases from 0 to $-6 ms^{-1}$.



Acceleration of the car

$$|a| = \left|\frac{v-u}{t}\right| = \frac{6-0}{1} = 6 ms^{-2}$$

The displacement of the particle is given as

$$s = ut + \frac{1}{2}at^2$$

For $t = 0$ to $t = 1$ s,

$$u = 0, a = +6 m/s^2$$

$$\Rightarrow s_1 = 0 + \frac{1}{2} \times 6 \times (1)^2 = 3 \text{ m}$$

For $t = 1$ s to $t = 2$ s,

$$u = 6 ms^{-1}, a = -6 ms^{-2}$$

$$\Rightarrow s_2 = 6 \times 1 - \frac{1}{2} \times 6 \times (1)^2 = 6 - 3 = 3 \text{m}$$

For $t = 2$ s to $t = 3$ s,

$$u = 0, a = -6 ms^{-1}$$

$$\Rightarrow s_3 = 0 - \frac{1}{2} \times 6 \times (1)^2 = -3 \text{m}$$

∴ Net displacement, $s = s_1 + s_2 + s_3$

$= 3 \text{m} + 3 \text{m} - 3 \text{m} = 3 \text{m}$

Hence, average velocity

$$= \frac{\text{Net displacement}}{\text{Total time}} = \frac{3}{3} = 1 \text{m s}^{-1}$$

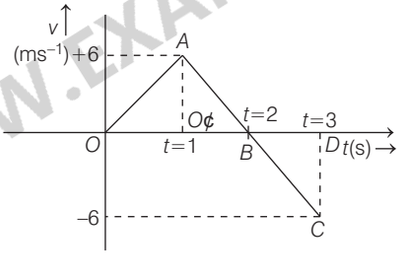
Total distance travelled, $d = 9$m

Hence, average speed $= \frac{\text{Total distance}}{\text{Total time}}$

$$= \frac{9}{3} = 3 \text{ m s}^{-1}$$

Alternative Method

Given condition can be represented through graph also as shown below.



∴ Displacement in three seconds

= Area under the graph

= Area of $\Delta OAO'$ + Area of $\Delta AO'B$ – Area of ΔBCD

$$= \frac{1}{2} \times 1 \times 6 + \frac{1}{2} \times 1 \times 6 - \frac{1}{2} \times 6 \times 1 = 3 \text{m}$$

∴ Average velocity $= \frac{3}{3} = 1 ms^{-1}$.

Total distance travelled, $d = 9$m

∴ Average speed $= \frac{9}{3} = 3 ms^{-1}$

29. A stone falls freely under gravity. It covers distances h_1, h_2 and h_3 in the first 5s, the next 5s and the next 5s respectively. The relation between h_1, h_2 and h_3 is **[NEET 2013]**

(a) $h_1 = 2h_2 = 3h_3$
(b) $h_1 = \frac{h_2}{3} = \frac{h_3}{5}$
(c) $h_2 = 3h_1$ and $h_3 = 3h_2$
(d) $h_1 = h_2 = h_3$

Ans. *(b)*

For free fall from a height, $u = 0$

∴ Distance covered by stone in first 5 s,

$$h_1 = 0 + \frac{1}{2}g(5)^2 = \frac{25}{2}g \quad \ldots(i)$$

∴ Distance covered in first 10 s,

$$s_2 = 0 + \frac{1}{2}g(10)^2 = \frac{100}{2}g$$

∴ Distance covered in second 5 s

$$h_2 = s_2 - h_1 = \frac{100}{2}g - \frac{25}{2}g = \frac{72}{2}g \ldots(ii)$$

Distance covered in first 15 s,

$$s_3 = 0 + \frac{1}{2}g(15)^2 = \frac{225}{2}g$$

∴ Distance covered in last 5 s,

$$h_3 = s_3 - s_2 = \frac{225}{2}g - \frac{100}{2}g = \frac{125}{2}g \ldots(iii)$$

From Eqs. (i), (ii) and (iii), we get

$$h_1 : h_2 : h_3 = \frac{25}{2}g : \frac{75}{2}g : \frac{125}{2}g = 1 : 3 : 5$$

$$\Rightarrow h_1 = \frac{h_2}{3} = \frac{h_3}{5}$$

30. A boy standing at the top of a tower of 20 m height drops a stone. Assuming, $g = 10 \text{ ms}^{-2}$, the velocity with which it hits the ground is **[CBSE AIPMT 2011]**

(a) 20 m/s (b) 40 m/s
(c) 5 m/s (d) 10 m/s

Ans. *(a)*

Given, $g = 10 \text{ m/s}^2$ and $h = 20$ m

We have $v = \sqrt{2gh} = \sqrt{2 \times 10 \times 20}$

$$= \sqrt{400} = 20 \text{ m/s}$$

31. A ball is dropped from a high rise platform at $t = 0$ starting from rest. After 6 s, another ball is thrown downwards from the same platform with a speed v. The two balls meet at $t = 18$ s. What is the value of v? (Take $g = 10 ms^{-2}$) **[CBSE AIPMT 2010]**

(a) 74 ms^{-1}
(b) 55 ms^{-1}
(c) 40 ms^{-1}
(d) 60 ms^{-1}

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Ans. *(a)*

For first ball, $u = 0$

$\therefore \quad s_1 = \frac{1}{2} g t_1^2 = \frac{1}{2} \times g (18)^2$

For second ball, initial velocity $= v$

$\therefore \quad s_2 = v t_2 + \frac{1}{2} g t^2$

$t_2 = 18 - 6 = 12\,\text{s}$

$\Rightarrow \quad s_2 = v \times 12 + \frac{1}{2} g (12)^2$

Here, $s_1 = s_2$

$\frac{1}{2} g (18)^2 = 12v + \frac{1}{2} g (12)^2$

$\Rightarrow \quad v = 74\ \text{ms}^{-1}$

32. A particle starts its motion from rest under the action of a constant force. If the distance covered in first 10 s is s_1 and that covered in the first 20 s is s_2, then **[CBSE AIPMT 2009]**

(a) $s_2 = 2\, s_1$ (b) $s_2 = 3\, s_1$
(c) $s_2 = 4\, s_1$ (d) $s_2 = s_1$

Ans. *(c)*

Since, the body starts from rest $u = 0$

$\therefore \quad s = \frac{1}{2} a t^2$

Now, $s_1 = \frac{1}{2} a (10)^2$ ...(i)

and $s_2 = \frac{1}{2} a (20)^2$ ...(ii)

Dividing Eq. (i) and Eq. (ii), we get

$\frac{s_1}{s_2} = \frac{(10)^2}{(20)^2}$

$\Rightarrow \quad s_2 = 4 s_1$

33. A particle moves in a straight line with a constant acceleration. It changes its velocity from $10\ \text{ms}^{-1}$ to $20\ \text{ms}^{-1}$ while passing through a distance 135 m in t sec. The value of t is **[CBSE AIPMT 2008]**

(a) 10 (b) 1.8
(c) 12 (d) 9

Ans. *(d)*

Using $v^2 - u^2 = 2as$

$(20)^2 - (10)^2 = 2 \times a \times 135$

$\Rightarrow \quad \frac{300}{270} = a = \frac{10}{9}$

Now, using $v - u = at$

$20 - 10 = \frac{10}{9} \times t$

$\Rightarrow \quad t = 9\,\text{s}$

34. The distance travelled by a particle starting from rest and moving with an acceleration $\frac{4}{3}\ \text{ms}^{-2}$, in the third-second is **[CBSE AIPMT 2008]**

(a) 6 m (b) 4 m
(c) $\frac{10}{3}$ m (d) $\frac{19}{3}$ m

Ans. *(c)*

Distance travelled in n^{th} second is given by

$s_n = u + \frac{1}{2} a (2n - 1)$

Here, $u = 0,\ a = \frac{4}{3}$

$\therefore \quad s_3 = 0 + \frac{1}{2} \times \frac{4}{3} \times (6 - 1) = \frac{10}{3}\ \text{m}$

35. Two bodies A (of mass 1 kg) and B (of mass 3 kg) are dropped from heights of 16 m and 25 m, respectively. The ratio of the time taken by them to reach the ground is **[CBSE AIPMT 2006]**

(a) –5 /4 (b) 12 /5
(c) 5/12 (d) 4/5

Ans. *(d)*

For free fall from a height, $u = 0$ (initial velocity).

From second equation of motion

$h = ut + \frac{1}{2} g t^2$

or $h = 0 + \frac{1}{2} g t^2$

$\therefore \quad \frac{h_1}{h_2} = \left(\frac{t_1}{t_2} \right)^2$

Given, $h_1 = 16\,\text{m}, h_2 = 25\,\text{m}$

$\therefore \quad \frac{t_1}{t_2} = \sqrt{\frac{h_1}{h_2}} = \sqrt{\frac{16}{25}} = \frac{4}{5}$

36. A man throws balls with the same speed vertically upwards one after the other at an interval of 2 s. What should be the speed of the throw so that more than two balls are in the sky at any time? (Take $g = 9.8\,\text{m/s}^2$) **[CBSE AIPMT 2003]**

(a) Any speed less than 19.6 m/s
(b) Only with speed 19.6 m/s
(c) More than 19.6 m/s
(d) At least 9.8 m/s

Ans. *(c)*

From equation of motion time taken by ball to reach maximum height $v = u - gt$

At maximum height, final speed is zero i.e. $v = 0$

So, $u = gt$ or $t = \frac{u}{g}$

In 2 s, $u = 2 \times 9.8 = 19.6\ \text{m/s}$

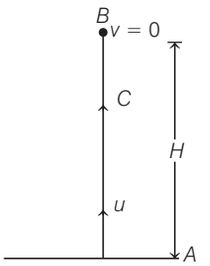
If man throws the ball with velocity of 19.6 m/s then after 2 s it will reach the maximum height. When he throws 2nd ball, 1st is at top. When he throws third ball, 1st will come to ground and 2nd will be at the top. Therefore, only 2 balls are in air. If he wants to keep more than 2 balls in air he should throw the ball with a speed greater than 19.6 m/s.

37. If a ball is thrown vertically upwards with speed u, the distance covered during the last t sec of its ascent is **[CBSE AIPMT 2003]**

(a) $ut - \frac{1}{2} g t^2$ (b) $(u + gt)\, t$
(c) ut (d) $\frac{1}{2} g t^2$

Ans. *(d)*

Let the ball takes T second to reach maximum height H. $v = u - gT$



put $v = 0$

(at height H)

$\therefore \quad u = gT$

or $T = \frac{u}{g}$ ...(i)

Velocity attained by the ball in $(T - t)$ s is,

$v' = u - g(T - t) = u - gT + gt$

$= u - g \frac{u}{g} + gt = u - u + gt$

$v' = gt$ ...(ii)

Hence, distance travelled in last t sec of its ascent

$CB = v't - \frac{1}{2} g t^2 = (gt)\, t - \frac{1}{2} g t^2$

$= gt^2 - \frac{1}{2} g t^2$ [From Eq. (ii)]

$= \frac{1}{2} g t^2$

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38. A stone is thrown vertically upwards. When stone is at a height half of its maximum height, its speed is 10 m/s, then the maximum height attained by the stone is ($g = 10\,\mathbf{m/s^2}$) **[CBSE AIPMT 2001]**

(a) 8 m (b) 10 m
(c) 15 m (d) 20 m

Ans. *(b)*

Let u be the initial velocity and H be the maximum height attained.

At height $h = \frac{H}{2}$, we have $v = v_1 = 10$ m/s

From third equation of motion,

$$v_1^2 = u^2 - 2gh$$

(Negative sign indicates that velocity and acceleration are in opposite direction)

or $(10)^2 = u^2 - 2g\frac{H}{2}$ ...(i)

At height H, $v_2 = 0$

$$v_2^2 = u^2 - 2gH \quad \text{or} \quad 0 = u^2 - 2gH \quad ...(ii)$$

Subtract Eq. (ii) from Eq. (i), we get

$$(10)^2 = 2g\frac{H}{2} \quad \text{or} \quad H = \frac{(10)^2}{g}$$

or $$H = \frac{(10)^2}{10} = 10\,\text{m}$$

Alternative

Maximum height attained by the stone

$$H = \frac{u^2}{2g}$$

When, $H = \frac{H}{2}$, $u = 10$ m/s

$$\frac{H}{2} = \frac{(10)^2}{2g} \quad \text{or } H = \frac{100}{10} = 10\,\text{m}$$

39. A car moving with a speed of 40 km/h can be stopped after 2 m by applying brakes. If the same car is moving with a speed of 80 km/h, what is the minimum stopping distance? **[CBSE AIPMT 1998]**

(a) 8 m (b) 2 m
(c) 4 m (d) 6 m

Ans. *(a)*

According to conservation of energy, the kinetic energy of car = work done in stopping the car

i.e. $$\frac{1}{2}mv^2 = Fs$$

where, F is the retarding force and s is the stopping distance.

For same retarding force,

$$s \propto v^2$$

$$\therefore \quad \frac{s_2}{s_1} = \left(\frac{v_2}{v_1}\right)^2 = \left(\frac{80}{40}\right)^2 = 4$$

$$\therefore \quad s_2 = 4s_1 = 4 \times 2 = 8\,\text{m}$$

Alternative

Initial speed of car $u = 40\,\text{km/h}$

$$= 40 \times \frac{5}{18}\,\text{m/s} = \frac{100}{9}\,\text{m/s}$$

From 3rd equation of motion,

$$v^2 = u^2 - 2as$$

$$\Rightarrow \quad 0 = \left(\frac{100}{9}\right)^2 - 2 \times a \times 2$$

$$4a = \frac{100 \times 100}{81}$$

$$\Rightarrow \quad a = \frac{2500}{81}\,\text{m/s}^2$$

Final speed of car = 80 km/h

$$= 80 \times \frac{5}{18} = \frac{200}{9}\,\text{m/s}$$

Suppose car stops for a distance s'.

Then

$$v^2 = u^2 - 2as'$$

$$0 = \left(\frac{200}{9}\right)^2 - 2 \times \frac{2500}{81}s'$$

$$\Rightarrow \quad s' = \frac{200 \times 200 \times 81}{9 \times 9 \times 2 \times 2500} = 8\,\text{m}$$

40. If a car at rest, accelerates uniformly to a speed of $144\,\mathbf{km/h}$ in 20s, it covers a distance of **[CBSE AIPMT 1997]**

(a) 2880 m (b) 1440 m
(c) 400 m (d) 20 m

Ans. *(c)*

Concept First of all find acceleration from the given values and then using equation of motion calculate distance travelled.

Given,

Initial velocity $u = 0$, time $t = 20$s

Final velocity $v = 144$ km/h $= 40$ m/s

From 1st equation of motion,

$$v = u + at$$

$$\Rightarrow \quad a = \frac{v - u}{t} = \frac{40 - 0}{20} = 2\,\text{m/s}^2$$

Now, from 2nd equation of motion,

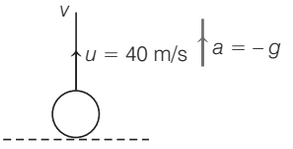
distance covered, $s = ut + \frac{1}{2}at^2$

$$= 0 + \frac{1}{2} \times 2 \times (20)^2 = 400\,\text{m}$$

41. If a ball is thrown vertically upwards with a velocity of $40\,\mathbf{m/s}$, then velocity of the ball after 2s will be ($g = 10\,\text{m/s}^2$) **[CBSE AIPMT 1996]**

(a) 15 m/s (b) 20 m/s
(c) 25 m/s (d) 28 m/s

Ans. *(b)*



Here, initial velocity of ball $u = 40$ m/s

Acceleration of ball $a = -g\,\text{m/s}^2$

$= -10\,\text{m/s}^2$

Time = 2 s

From first equation of motion,

$$v = u + at = 40 - 10 \times 2$$

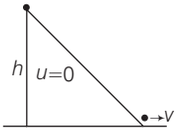
$$\Rightarrow \quad v = 20\,\text{m/s}$$

42. Three different objects of masses m_1, m_2 and m_3 are allowed to fall from rest and from the same point O along three different frictionless paths. The speeds of the three objects on reaching the ground will be in the ratio of **[CBSE AIPMT 1995]**

(a) $m_1 : m_2 : m_3$
(b) $m_1 : 2m_2 : 3m_3$
(c) 1:1:1
(d) $\frac{1}{m_1} : \frac{1}{m_2} : \frac{1}{m_3}$

Ans. *(c)*

When an object falls freely under gravity, then its speed depends only on its height of fall and is independent of the mass of the object. As all objects are falling through the same height, therefore their speeds on reaching the ground will be in the ratio of 1 : 1 : 1.



Alternative

The vertical displacement for all the three is same and paths are frictionless. So, by conservation of mechanical energy,

$$\frac{1}{2}mv^2 = mgl$$

$$\Rightarrow \quad v = \sqrt{2gl}$$

So, $v_1 : v_2 : v_3 = 1 : 1 : 1$

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43. The water drops fall at regular intervals from a tap 5 m above the ground. The third drop is leaving the tap at an instant when the first drop touches the ground. How far above the ground is the second drop at that instant ? (Take $g = 10\,\text{m/s}^2$) **[CBSE AIPMT 1995]**

(a) 1.25 m
(b) 2.50 m
(c) 3.75 m
(d) 5.00 m

Ans. *(c)*

Let t be the time interval of two drops.
For third drop to fall

$$5 = \frac{1}{2} g (2t)^2 \qquad [\text{As } u = 0]$$

or $$\frac{1}{2} gt^2 = \frac{5}{4} \qquad ...(i)$$

Let x be the distance through which second drop falls for time t, then

$$x = \frac{1}{2} gt^2 = \frac{5}{4}\text{m} \qquad [\text{from Eq. (i)}]$$

Thus, height of second drop from ground

$$= 5 - \frac{5}{4} = \frac{15}{4} = 3.75\,\text{m}$$

44. A body is thrown vertically upwards from the ground. It reaches a maximum height of 20 m in 5 s. After what time it will reach the ground from its maximum height position ? **[CBSE AIPMT 1995]**

(a) 2.5 s (b) 5 s
(c) 10 s (d) 25 s

Ans. *(b)*

Time taken by the body to reach the ground from some height is the same as taken to reach that height. Hence, time to reach the ground from its maximum height is 5 s.

45. A stone released with zero velocity from the top of a tower, reaches the ground in 4 s. The height of the tower is $(g = 10\,\text{m/s}^2)$ **[CBSE AIPMT 1995]**

(a) 20 m (b) 40 m
(c) 80 m (d) 160 m

Ans. *(c)*

Initial velocity of stone $u = 0$
Time to reach at ground $t = 4$ s
Acceleration $a = +g = 10\ \text{m/s}^2$

(As motion of body is along the acceleration due to gravity.)

∴ Height of tower

$$h = ut + \frac{1}{2} gt^2 = (0 \times 4) + \frac{1}{2} \times 10 \times 4^2$$

$$= 80\ \text{m}$$

46. A body starts from rest, what is the ratio of the distance travelled by the body during the 4th and 3rd s? **[CBSE AIPMT 1993]**

(a) $\frac{7}{5}$ (b) $\frac{5}{7}$ (c) $\frac{7}{3}$ (d) $\frac{3}{7}$

Ans. *(a)*

Distance travelled by the body in nth second is given by

$$s_n = u + \frac{a}{2}(2n - 1)$$

Here, $u = 0$

∴ For 4th s, $s_4 = \frac{a}{2}(2 \times 4 - 1)$

and For 3th s, $s_3 = \frac{a}{2}(2 \times 3 - 1)$

Hence, $$\frac{s_4}{s_3} = \frac{(2 \times 4 - 1)}{(2 \times 3 - 1)} = \frac{7}{5}$$

47. A body dropped from top of a tower fall through 40 m during the last two seconds of its fall. The height of tower is $(g = 10\,\text{m/s}^2)$ **[CBSE AIPMT 1991]**

(a) 60 m (b) 45 m
(c) 80 m (d) 50 m

Ans. *(b)*

Let the body falls through the height of tower in t seconds.

From $s_n = u + \frac{a}{2}(2n - 1)$, we have

Total distance travelled in last 2 s of fall is

$$s = s_t + s_{(t-1)}$$

$$= \left[0 + \frac{g}{2}(2t - 1)\right] + \left[0 + \frac{g}{2}(2(t - 1) - 1)\right]$$

$$= \frac{g}{2}(2t - 1) + \frac{g}{2}(2t - 3)$$

$$= \frac{g}{2}(4t - 4) = \frac{10}{2} \times 4(t - 1)$$

or $40 = 20(t - 1)$ or $t = 2 + 1 = 3$ s

Distance travelled in t sec is

$$s = ut + \frac{1}{2} at^2$$

$$= 0 + \frac{1}{2} \times 10 \times 3^2 = 45\ \text{m}$$

48. What will be the ratio of the distance moved by a freely falling body from rest in 4th and 5th second of journey? **[CBSE AIPMT 1989]**

(a) 4 : 5 (b) 7 : 9
(c) 16 : 25 (d) 1 : 1

Ans. *(b)*

As distance travelled in n^{th} sec is given by

$$s_n = u + \frac{1}{2} a (2n - 1)$$

Here, $u = 0$, acceleration due to gravity

$$a = 9.8\ \text{m/s}^2$$

∴ For 4th s, $s_4 = \frac{1}{2} \times 9.8 (2 \times 4 - 1)$

and for 5th s, $s_5 = \frac{1}{2} \times 9.8 (2 \times 5 - 1)$

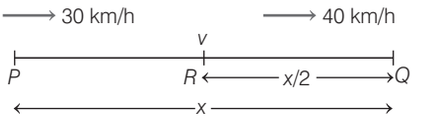
∴ $$\frac{s_4}{s_5} = \frac{7}{9}$$

49. A car is moving along a straight road with a uniform acceleration. It passes through two points P and Q separated by a distance with velocity 30 km/h and 40 km/h respectively. The velocity of the car midway between P and Q is **[CBSE AIPMT 1988]**

(a) 33.3 km/h (b) $20\sqrt{2}$ km/h
(c) $25\sqrt{2}$ km/h (d) 0.35 km/h

Ans. *(c)*

Let x be the total distance between points P and Q and v be the velocity of car while passing a certain middle point of PQ. If a is the acceleration of the car, then



For part PQ,

$$40^2 - 30^2 = 2ax$$

or $$a = \frac{350}{x} \qquad ...(i)$$

For part RQ,

$$40^2 - v^2 = \frac{2ax}{2} \qquad ...(ii)$$

Putting value of a from Eq. (i) in Eq. (ii), we have

$$40^2 - v^2 = 2\left(\frac{350}{x}\right)\frac{x}{2}$$

or $$40^2 - v^2 = 350 \quad \text{or} \quad v^2 = 1250$$

⇒ $$v = 25\sqrt{2}\ \text{km/h}$$

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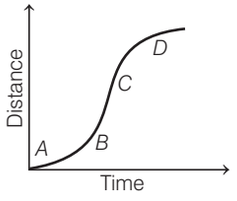
TOPIC 3
Graphs in Motion

50. A particle shows distance-time curve as given in this figure. The maximum instantaneous velocity of the particle is around the point **[CBSE AIPMT 2008]**



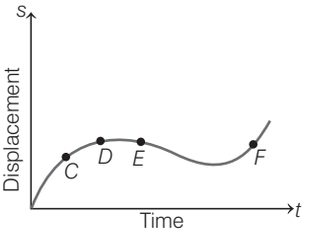
(a) B (b) C
(c) D (d) A

Ans. ***(b)***

Maximum velocity point means, the point at which $\frac{dx}{dt}$ i.e. the slope of the graph is maximum.

At point C, slope is maximum.

51. The displacement-time graph of moving particle is shown below.



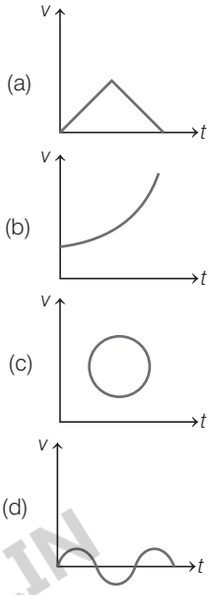
The instantaneous velocity of the particle is negative at the point **[CBSE AIPMT 1994]**

(a) D
(b) F
(c) C
(d) E

Ans. ***(d)***

Instantaneous velocity is the slope of displacement-time graph. At point E, the slope is negative so instantaneous velocity of the particle is negative. At points C and F, the slope is positive and at D, the slope is zero.

52. Which of the following curves does not represent motion in one dimension? **[CBSE AIPMT 1992]**



Ans. ***(c)***

In option (c), particle have two velocities at a particular instant of time, which is impossible.

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03
Motion in a Plane

TOPIC 1
Vectors

01 If the magnitude of sum of two vectors is equal to the magnitude of difference of the two vectors, the angle between these vectors is **[NEET 2016, CBSE AIPMT 1991]**

(a) 90° (b) 45°
(c) 180° (d) 0°

Ans. *(a)*

Suppose two vectors are **P** and **Q**.

It is given that

$$|\mathbf{P}+\mathbf{Q}|=|\mathbf{P}-\mathbf{Q}|$$

Let angle between **P** and **Q** is ϕ.

$$\therefore \quad P^2+Q^2+2PQ\cos\phi = P^2+Q^2-2PQ\cos\phi$$

$$\Rightarrow \quad 4PQ\cos\phi = 0$$

$$\Rightarrow \quad \cos\phi = 0 \qquad [\because P, Q \neq 0]$$

$$\Rightarrow \quad \phi = \frac{\pi}{2} = 90°$$

02 If vectors $\mathbf{A}=\cos\omega t\,\hat{\mathbf{i}}+\sin\omega t\,\hat{\mathbf{j}}$ and $\mathbf{B}=\cos\frac{\omega t}{2}\hat{\mathbf{i}}+\sin\frac{\omega t}{2}\hat{\mathbf{j}}$ are functions of time, then the value of t at which they are orthogonal to each other, is **[CBSE AIPMT 2015]**

(a) $t=\frac{\pi}{4\omega}$ (b) $t=\frac{\pi}{2\omega}$

(c) $t=\frac{\pi}{\omega}$ (d) $t=0$

Ans. *(c)*

For perpendicular vector, we have

$$\mathbf{A}\cdot\mathbf{B}=0$$

$$[\cos\omega t\hat{\mathbf{i}}+\sin\omega t\hat{\mathbf{j}}]\left[\cos\frac{\omega t}{2}\hat{\mathbf{i}}+\frac{\sin\omega t}{2}\hat{\mathbf{j}}\right]=0$$

$$\Rightarrow \quad \cos\omega t\cos\frac{\omega t}{2}+\sin\omega t\sin\frac{\omega t}{2}=0$$

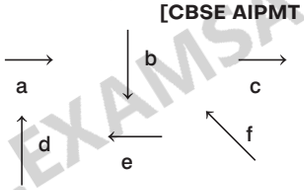
$$[\because \cos(A-B)=\cos A\cos B+\sin A\sin B]$$

$$\Rightarrow \quad \cos\left(\omega t-\frac{\omega t}{2}\right)=0 \Rightarrow \quad \cos\frac{\omega t}{2}=0$$

$$\Rightarrow \quad \frac{\omega}{2}=\frac{\pi}{2} \Rightarrow t=\frac{\pi}{\omega}$$

Thus, time taken by vectors which are orthogonal to each other is $\frac{\pi}{\omega}$.

03 Six vectors **a** to **f** have the magnitudes and directions indicated in the figure. Which of the following statements is true? **[CBSE AIPMT 2010]**



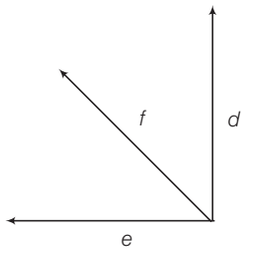
(a) b + c = f (b) d + c = f

(c) d + e = f (d) b + e = f

Ans. *(c)*

If two non-zero vectors are represented by the two adjacent sides of a parallelogram, then the resultant is given by the diagonal of the parallelogram passing through the point of intersection of the two vectors

$$\therefore \quad \mathbf{d}+\mathbf{e}=\mathbf{f}$$



04 A and B are two vectors and θ is the angle between them. If $|A\times B|=\sqrt{3}(A\cdot B)$, then the value of θ is **[CBSE AIPMT 2007]**

(a) 60° (b) 45° (c) 30° (d) 90°

Ans. *(a)*

Given, $|\mathbf{A}\times\mathbf{B}|=\sqrt{3}(\mathbf{A}\cdot\mathbf{B})$

$$\Rightarrow \quad AB\sin\theta=\sqrt{3}\,AB\cos\theta$$

$$\Rightarrow \quad \tan\theta=\sqrt{3}$$

$$\therefore \quad \theta=60°$$

05 If a vector $2\hat{\mathbf{i}}+3\hat{\mathbf{j}}+8\hat{\mathbf{k}}$ is perpendicular to the vector $4\hat{\mathbf{j}}-4\hat{\mathbf{i}}+\alpha\hat{\mathbf{k}}$, then the value of α is **[CBSE AIPMT 2005]**

(a) -1 (b) $\frac{1}{2}$ (c) $-\frac{1}{2}$ (d) 1

Ans. *(c)*

Concept If two vectors are perpendicular to each other than their dot product is always equal to zero.

Let, $\mathbf{a}=2\hat{\mathbf{i}}+3\hat{\mathbf{j}}+8\hat{\mathbf{k}}$

$$\mathbf{b}=4\hat{\mathbf{j}}-4\hat{\mathbf{i}}+\alpha\hat{\mathbf{k}}=-4\hat{\mathbf{i}}+4\hat{\mathbf{j}}+\alpha\hat{\mathbf{k}}$$

According to the above hypothesis

$$\mathbf{a}\perp\mathbf{b}$$

$$\Rightarrow \quad \mathbf{a}\cdot\mathbf{b}=0$$

$$\Rightarrow \quad (2\hat{\mathbf{i}}+3\hat{\mathbf{j}}+8\hat{\mathbf{k}})\cdot(-4\hat{\mathbf{i}}+4\hat{\mathbf{j}}+\alpha\hat{\mathbf{k}})=0$$

$$\Rightarrow \quad -8+12+8\alpha=0$$

$$\Rightarrow \quad 8\alpha=-4$$

$$\therefore \quad \alpha=-\frac{4}{8}=-\frac{1}{2}$$

06 If $|\mathbf{A}\times\mathbf{B}|=\sqrt{3}\,\mathbf{A}\cdot\mathbf{B}$, then the value of $|\mathbf{A}+\mathbf{B}|$ is **[CBSE AIPMT 2004]**

(a) $(A^2+B^2+AB)^{1/2}$

(b) $\left(A^2+B^2+\frac{AB}{\sqrt{3}}\right)^{1/2}$

(c) $A+B$

(d) $(A^2+B^2+\sqrt{3}\,AB)^{1/2}$

Ans. *(a)*

Given, $|\mathbf{A}\times\mathbf{B}|=\sqrt{3}\,\mathbf{A}\cdot\mathbf{B}$ ...(i)

but $|\mathbf{A}\times\mathbf{B}|=|\mathbf{A}||\mathbf{B}|\sin\theta=AB\sin\theta$

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and $\mathbf{A}\cdot\mathbf{B}=|\mathbf{A}||\mathbf{B}|\cos\theta=AB\cos\theta$

Substituting these values in Eq. (i), we get

$$AB\sin\theta=\sqrt{3}\,AB\cos\theta$$

or $\tan\theta=\sqrt{3}$

$\therefore$ $\theta=60°$

The addition of vectors **A** and **B** can be given by the law of parallelogram.

$$\therefore\quad |\mathbf{A}+\mathbf{B}|=\sqrt{A^2+B^2+2AB\cos60°}$$
$$=\sqrt{A^2+B^2+2AB\times\frac{1}{2}}$$
$$=(A^2+B^2+AB)^{1/2}$$

07 The vector sum of two forces is perpendicular to their vector differences. In that case, the forces **[CBSE AIPMT 2003]**

(a) are not equal to each other in magnitude
(b) cannot be predicted
(c) are equal to each other
(d) are equal to each other in magnitude

Ans. *(d)*

Let **A** and **B** be two forces. The sum of the two forces.

$$\mathbf{F}_1=\mathbf{A}+\mathbf{B} \quad ...(i)$$

The difference of the two forces,

$$\mathbf{F}_2=\mathbf{A}-\mathbf{B} \quad ...(ii)$$

Since, sum of the two forces is perpendicular to their differences as given, so

$$\mathbf{F}_1\cdot\mathbf{F}_2=0$$

or $(\mathbf{A}+\mathbf{B})\cdot(\mathbf{A}-\mathbf{B})=0$

or $A^2-\mathbf{A}\cdot\mathbf{B}+\mathbf{B}\cdot\mathbf{A}-B^2=0$

or $A^2=B^2$ or $|\mathbf{A}|=|\mathbf{B}|$

Thus, the forces are equal to each other in magnitude.

08 If a unit vector is represented by $0.5\hat{\mathbf{i}}+0.8\hat{\mathbf{j}}+c\hat{\mathbf{k}}$, then the value of c is **[CBSE AIPMT 1999]**

(a) 1 (b) $\sqrt{0.11}$ (c) $\sqrt{0.01}$ (d) 0.39

Ans. *(b)*

Concept Unit vector can be found by dividing a vector with its magnitude i.e. $\mathbf{A}=\frac{\mathbf{A}}{|\mathbf{B}|}$

Let we represent the unit vector by $\hat{\mathbf{n}}$.

We also know that the modulus of unit vector is 1 i.e., $|\hat{\mathbf{n}}|=1$

$$\therefore\quad |\hat{\mathbf{n}}|=|0.5\hat{\mathbf{i}}+0.8\hat{\mathbf{j}}+c\hat{\mathbf{k}}|=1$$

or $\sqrt{(0.5)^2+(0.8)^2+c^2}=1$

or $0.25+0.64+c^2=1$

or $0.89+c^2=1$

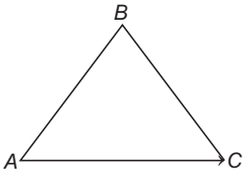
or $c^2=1-0.89=0.11\Rightarrow c=\sqrt{0.11}$

09 Which of the following is not a vector quantity? **[CBSE AIPMT 1995]**

(a) Speed (b) Velocity
(c) Torque (d) Displacement

Ans. *(a)*

Speed is a scalar quantity. It gives no idea about the direction of motion of the object. Velocity is a vector quantity, as it has both magnitude and direction. Displacement is a vector as it possesses both magnitude and direction. When an object goes on the path *ABC* (in figure), then the displacement of the object is **AC**. The arrow head at *C* shows that the object is displaced from *A* to *C*.



Torque is turning effect of force which is a vector quantity.

10 The angle between the two vectors $\mathbf{A}=3\hat{\mathbf{i}}+4\hat{\mathbf{j}}+5\hat{\mathbf{k}}$ and $\mathbf{B}=3\hat{\mathbf{i}}+4\hat{\mathbf{j}}-5\hat{\mathbf{k}}$ will be **[CBSE AIPMT 1994]**

(a) 0° (b) 45° (c) 90° (d) 180°

Ans. *(c)*

Angle between two vectors is given as from dot product $\mathbf{A}\cdot\mathbf{B}=|\mathbf{A}||\mathbf{B}|\cos\theta$

$$\cos\theta=\frac{\mathbf{A}\cdot\mathbf{B}}{AB}$$

Here, $\mathbf{A}=3\hat{\mathrm{i}}+4\hat{\mathrm{j}}+5\hat{\mathrm{k}}$

$\mathbf{B}=3\hat{\mathrm{i}}+4\hat{\mathrm{j}}-5\hat{\mathrm{k}}$

$$\therefore\quad A=\sqrt{(3)^2+(4)^2+(5)^2}=\sqrt{50}$$
$$B=\sqrt{(3)^2+(4)^2+(-5)^2}=\sqrt{50}$$

and $\mathbf{A}\cdot\mathbf{B}=(3\hat{\mathrm{i}}+4\hat{\mathrm{j}}+5\hat{\mathrm{k}})\cdot(3\hat{\mathrm{i}}+4\hat{\mathrm{j}}-5\hat{\mathrm{k}})$

$=9+16-25=0$

$$\therefore\quad \cos\theta=\frac{0}{\sqrt{50}\cdot\sqrt{50}}=0$$

$\Rightarrow$ $\theta=90°$

11 The resultant of $\mathbf{A}\times0$ will be equal to **[CBSE AIPMT 1992]**

(a) zero (b) A
(c) zero vector (d) unit vector

Ans. *(c)*

From the properties of vector product, the cross product of any vector with zero is a null vector or zero vector.

12 The angle between **A** and **B** is θ. The value of the triple product $\mathbf{A}\cdot(\mathbf{B}\times\mathbf{A})$ is **[CBSE AIPMT 1989]**

(a) A^2B (b) zero
(c) $A^2B\sin\theta$ (d) $A^2B\cos\theta$

Ans. *(b)*

In scalar triple product of vectors, the positions of dot and cross can be interchanged, i.e.

$$\mathbf{A}\cdot(\mathbf{B}\times\mathbf{A})=(\mathbf{A}\times\mathbf{B})\cdot\mathbf{A}=(\mathrm{A}\times\mathrm{A})\cdot\mathrm{B}$$

but $\mathbf{A}\times\mathbf{A}=0$

$\therefore$ $\mathbf{A}\cdot(\mathbf{B}\times\mathbf{A})=0$

Alternative

$$\mathbf{A}\cdot(\mathbf{B}\times\mathbf{A})$$

Let $\mathbf{A}\times\mathbf{B}=\mathbf{C}$

The direction of **C** is $\perp$ to **A** and **B** from cross product formula

So, $\mathbf{A}\cdot\mathbf{C}=0$

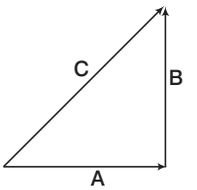
(since, **A** and **C** are $\perp$ to each other)

13 The magnitudes of vectors **A**, **B** and **C** are 3, 4 and 5 units respectively. If $\mathbf{A}+\mathbf{B}=\mathbf{C}$, the angle between **A** and **B** is **[CBSE AIPMT 1988]**

(a) $\frac{\pi}{2}$ (b) $\cos^{-1}(0.6)$
(c) $\tan^{-1}\left(\frac{7}{5}\right)$ (d) $\frac{\pi}{4}$

Ans. *(a)*

In figure shown, $\mathbf{A}+\mathbf{B}=\mathbf{C}$



Also, $|\mathbf{A}|=3$, $|\mathbf{B}|=4$, $|\mathbf{C}|=5$

As $\mathbf{A}+\mathbf{B}=\mathbf{C}$

So, $5^2=3^2+4^2+2\cdot4\cdot3\cos\theta$

$\cos\theta=0\Rightarrow\theta=\frac{\pi}{2}$

$\Rightarrow$ **A** is perpendicular to **B**.

TOPIC 2
Motion in a Plane and Projectile Motion

14 Two bullets are fired horizontally and simultaneously towards each other from roof tops of two buildings 100 m apart and of same height of 200 m with the same velocity of 25 m/s. When and where will the two bullets collides. ($g=10\,m/s^2$) **[NEET (Odisha) 2019]**

(a) After 2s at a height 180 m

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(b) After 2s at a height of 20 m
(c) After 4s at a height of 120 m
(d) They will not collide

Ans. *(a)*

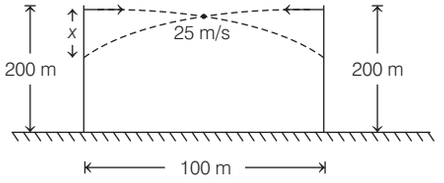
Given, distance between the two buildings

$$d = 100 \text{ m}$$

height of each tower, $h = 200$ m

speed of each bullet, $v = 25 \text{ ms}^{-1}$

The situation can be shown as below



where, x be the vertical distance travelled from the top of the building and t be the time at which they collide.

As two bullets are fired toward each other,

So, their relative velocity will be

$$v_{rel} = 25 - (-25) = 50 \text{ ms}^{-1}$$

Then, time $t = \frac{d}{v_{rel}} = \frac{100}{50} = 2 \text{ s}$

The distance or height at which they collide is calculated from equation of motion,

$$x = ut + \frac{1}{2}at^2$$

The bullet is initially a rest i.e. $u = 0$ and as it is moving under the effect of gravity $a = -g$, so

$$x = -\frac{1}{2}gt^2$$

$$x = -\frac{1}{2} \times 10(2)^2 = -20 \text{ m}$$

The negative sign shows that the bullets will collide 20 m below the top of tower i.e. at a height of $(200 - 20) = 180$ m from the ground after 2 s.

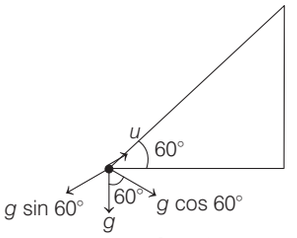
15 When an object is shot from the bottom of a long smooth inclined plane kept at an angle 60º with horizontal, it can travel a distance x_1 along the plane. But when the inclination is decreased to 30º and the same object is shot with the same velocity, it can travel x_2 distance.

Then $x_1 : x_2$ will be **[NEET (National) 2019]**

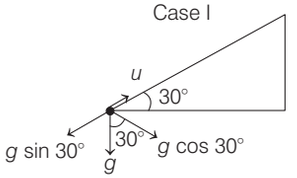
(a) $\sqrt{2}:1$ (b) $1:\sqrt{3}$
(c) $1:2\sqrt{3}$ (d) $1:\sqrt{2}$

Ans. *(b)*

The motion of object shot in two cases can be depicted as below



Case I



Case II

Using third equation of motion,

$$v^2 = u^2 - 2gh \quad \text{... (i)}$$

As the object stops finally, so

$$v = 0$$

For inclined motion,

$$g = g\sin\theta \text{ and } h = x$$

Substituting these values in Eq. (i), we get

$$\Rightarrow u^2 = 2g\sin\theta x \Rightarrow x = \frac{u^2}{2g\sin\theta}$$

For case (I), $x_1 = \frac{u^2}{2g\sin 60°}$

For case (II), $x_2 = \frac{u^2}{2g\sin 30°}$

$$\Rightarrow \frac{x_1}{x_2} = \frac{u^2}{2g\sin 60°} \times \frac{2g\sin 30°}{u^2}$$

$$= \frac{1}{2} \times \frac{2}{\sqrt{3}} = \frac{1}{\sqrt{3}} \text{ or } 1:\sqrt{3}$$

16 The x and y coordinates of the particle at any time are $x = 5t - 2t^2$ and $y = 10t$ respectively, where x and y are in metres and t in seconds. The acceleration of the particle at $t = 2$ s is **[NEET 2017]**

(a) 0 (b) 5 m/s^2
(c) -4 m/s^2 (d) -8 m/s^2

Ans. *(c)*

Given, $x = 5t - 2t^2$

Velocity of the particle,

$$v_x = \frac{dx}{dt} = \frac{d}{dt}(5t - 2t^2) = 5 - 4t$$

Acceleration, $a_x = \frac{d}{dt}v_x = -4 \text{ ms}^{-2}$

Also, $y = 10t$

Velocity, $v_y = \frac{dy}{dt} = 10$

$\therefore$ Acceleration $a_y = \frac{dv_y}{dt} = 0$

$\therefore$ Net acceleration of the particle,

$$\mathbf{a}_{net} = a_x\hat{\mathbf{i}} + a_y\hat{\mathbf{j}} = (-4 \text{ ms}^{-2})\hat{\mathbf{i}}$$

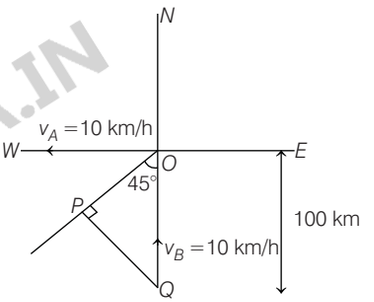
or $\mathbf{a}_{net} = -4\,\hat{\mathbf{i}} \text{ ms}^{-2}$

17 A ship A is moving Westwards with a speed of 10 km h^{-1} and a ship B 100 km South of A, is moving Northwards with a speed of 10 km h^{-1}. The time after which the distance between them becomes shortest is **[CBSE AIPMT 2015]**

(a) 0 h (b) 5 h
(c) $5\sqrt{2}$ h (d) $10\sqrt{2}$ h

Ans. *(b)*

It is clear from the diagram that the shortest distance between the ship A and B is PQ.



Here, $\sin 45° = \frac{PQ}{OQ} \Rightarrow PQ = 100 \times \frac{1}{\sqrt{2}}$

$= 50\sqrt{2}$ m

Also, $v_{AB} = \sqrt{v_A^2 + v_B^2} = \sqrt{10^2 + 10^2}$

$= 10\sqrt{2}$ km/h

So, time taken for them to reach shortest path is

$$t = \frac{PQ}{v_{AB}} = \frac{50\sqrt{2}}{10\sqrt{2}} = 5 \text{ h}$$

18 The position vector of a particle **R** as a function of time is given by

$$\mathbf{R} = 4\sin(2\pi t)\hat{\mathbf{i}} + 4\cos(2\pi t)\hat{\mathbf{j}}$$

where R is in metre, t is in seconds and $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$ denote unit vectors along x and y-directions, respectively. Which one of the following statements is wrong for the motion of particle? **[CBSE AIPMT 2015]**

(a) Acceleration is along $-$R
(b) Magnitude of acceleration vector is $\frac{v^2}{R}$, where v is the velocity of particle

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(c) Magnitude of the velocity of particle is 8 m/s

(d) Path of the particle is a circle of radius 4 m

Ans. *(c)*

(i) The position vector of a particle $\mathbf{R}$ as a function of time is given by

$$\mathbf{R} = 4\sin(2\pi t)\,\hat{\mathbf{i}} + 4\cos(2\pi t)\,\hat{\mathbf{j}}$$

x-axis component, $x = 4\sin 2\pi t$ ...(i)

y-axis component, $y = 4\cos 2\pi t$ ...(ii)

Squaring and adding both equations, we get

$x^2 + y^2 = 4^2[\sin^2(2\pi t) + \cos^2(2\pi t)]$

i.e. $x^2 + y^2 = 4^2$ i.e. equation of circle and radius is 4 m.

(ii) Acceleration vector, $\mathbf{a} = \frac{v^2}{R}(-\mathbf{R})$, while v is velocity of a particle.

(iii) Magnitude of acceleration vector,

$$a = \frac{v^2}{R}$$

(iv) As, we have $v_x = +4(\cos 2\pi t)\,2\pi$ and $v_y = -4(\sin 2\pi t)\,2\pi$

Net resultant velocity,

$$v = \sqrt{v_x^2 + v_y^2}$$

$$= \sqrt{(8\pi)^2(\cos^2 2\pi t + \sin^2 2\pi t)}$$

$v = 8\pi$ $[\because \cos^2 2\pi t + \sin^2 2\pi t = 1]$

So, option (c) is incorrect.

19 A projectile is fired from the surface of the earth with a velocity of 5 ms^{-1} at angle θ with the horizontal. Another projectile fired from another planet with a velocity of $3\,ms^{-1}$ at the same angle follows a trajectory which is identical with the trajectory of the projectile fired from the earth. The value of the acceleration due to gravity on the planet is (in ms^{-2}) is (given, $g = 9.8\ ms^{-2}$) **[CBSE AIPMT 2014]**

(a) 3.5 (b) 5.9 (c) 16.3 (d) 110.8

Ans. *(a)*

The trajectory of a projectile projected at some angle θ with the horizontal direction from ground is given by

$$y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}$$

For equal trajectories for same angle of projection,

$$\frac{g}{u^2} = \text{constant} \Rightarrow \frac{9.8}{5^2} = \frac{g'}{3^2}$$

$$g' = \frac{9.8\times 9}{25} = 3.5\ ms^{-2}$$

20 A particle is moving such that its position co-ordinates (x, y) are (2m, 3m) at time $t = 0$, (6m, 7m) at time $t = 2$ s and (13m, 14m) at time $t = 5$ s. Average velocity vector (v_{av}) from $t = 0$ to $t = 5$ s is **[CBSE AIPMT 2014]**

(a) $\frac{1}{5}(13\hat{\mathbf{i}} + 14\hat{\mathbf{j}})$ (b) $\frac{7}{3}(\hat{\mathbf{i}} + \hat{\mathbf{j}})$

(c) $2(\hat{\mathbf{i}} + \hat{\mathbf{j}})$ (d) $\frac{11}{5}(\hat{\mathbf{i}} + \hat{\mathbf{j}})$

Ans. *(d)*

Given, position vector of the particle at $t = 0$ is $(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}})$ and $t = 5$ s is $(13\hat{\mathbf{i}} + 14\hat{\mathbf{j}})$

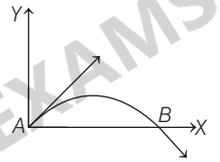
Average velocity vector

$$\mathbf{v}_{av} = \frac{\text{Net displacement}}{\text{Time taken}}$$

$$= \frac{(13-2)\hat{\mathbf{i}} + (14-3)\hat{\mathbf{j}}}{5}$$

$$= \frac{11\hat{\mathbf{i}} + 11\hat{\mathbf{j}}}{5} = \frac{11}{5}(\hat{\mathbf{i}} + \hat{\mathbf{j}})$$

21 The velocity of a projectile at the initial point A is $(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}})$ m/s. Its velocity (in m/s) at point B is **[NEET 2013]**



(a) $-2\hat{\imath} - 3\hat{\jmath}$ (b) $-2\hat{\imath} + 3\hat{\jmath}$

(c) $2\hat{\imath} - 3\hat{\jmath}$ (d) $2\hat{\imath} + 3\hat{\jmath}$

Ans. *(c)*

Concept As we know that in projectile motion only velocity of y component change, whereas velocity of x component remains constant.

From the figure, the x-component remains unchanged, while the y-component is reversed. Thus, the velocity at point B is $(2\hat{\mathbf{i}} - 3\hat{\mathbf{j}})\ ms^{-1}$.

22 The horizontal range and the maximum height of a projectile are equal. The angle of projection of the projectile is **[CBSE AIPMT 2012]**

(a) $\theta = \tan^{-1}\left(\frac{1}{4}\right)$ (b) $\theta = \tan^{-1}(4)$

(c) $\theta = \tan^{-1}(2)$ (d) $\theta = 45°$

Ans. *(b)*

Given, horizontal range

R = vertical maximum height H

$$\text{Range, } R = \frac{u^2(2\sin\theta\cos\theta)}{g}$$

$$\text{Height, } H = \frac{u^2\sin^2\theta}{2g}$$

$$\text{Hence, } \frac{u^2(2\sin\theta\cos\theta)}{g} = \frac{u^2\sin^2\theta}{2g}$$

$$2\cos\theta = \frac{\sin\theta}{2}$$

$\tan\theta = 4 \Rightarrow \theta = \tan^{-1}(4)$

23 A missile is fired for maximum range with an initial velocity of 20 m/s. If $g = 10\ m/s^2$, the range of the missile is **[CBSE AIPMT 2011]**

(a) 50 m (b) 60 m (c) 20 m (d) 40 m

Ans. *(d)*

For maximum range of projectile, θ will be 45° by the law of projectile motion.

So, maximum range, $R_{max} = \frac{u^2}{g}$

Given, $u = 20\ ms^{-1}$ and $g = 10\ ms^{-2}$

$$R_{max} = \frac{(20)^2}{10} = \frac{400}{10}$$

$R_{max} = 40$ m

24 A particle has initial velocity $(3\hat{\mathbf{i}} + 4\hat{\mathbf{j}})$ and has acceleration $(0.4\hat{\mathbf{i}} + 0.3\hat{\mathbf{j}})$. Its speed after 10 s is **[CBSE AIPMT 2010]**

(a) 7 unit (b) $7\sqrt{2}$ unit

(c) 8.5 unit (d) 10 unit

Ans. *(b)*

Given, initial velocity $(u) = 3\hat{\mathbf{i}} + 4\hat{\mathbf{j}}$

Final velocity $(v) = ?$

Acceleration $(a) = (0.4\,\hat{\mathbf{i}} + 0.3\hat{\mathbf{j}})$

Time $(t) = 10$ s

From first equation of motion, $v = u + at$

$$v = 3\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 10(0.4\hat{\mathbf{i}} + 0.3\hat{\mathbf{j}})$$

$$v = 7\hat{\mathbf{i}} + 7\hat{\mathbf{j}} \Rightarrow |v| = 7\sqrt{2}$$

25 A particle of mass m is projected with velocity v making an angle of 45° with the horizontal. When the particle lands on the level ground, the magnitude of the change in its momentum will be **[CBSE AIPMT 2008]**

(a) $2mv$ (b) $\frac{mv}{\sqrt{2}}$ (c) $mv\sqrt{2}$ (d) zero

Ans. *(c)*

$\Delta\mathbf{p} = m(\mathbf{v} - \mathbf{u})$

$$|\Delta\mathbf{p}| = |mv[\cos 45\hat{\mathbf{i}} - \sin 45\hat{\mathbf{j}}] - mv[\cos 45\hat{\mathbf{i}} + \sin 45\hat{\mathbf{j}}]|$$

$$= 2mv\sin 45° = \sqrt{2}\,mv$$

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Alternative

The α component of velocity will remain constant.

$$\Rightarrow \quad \Delta v_y = \frac{v}{\sqrt{2}} - \left(\frac{-v}{\sqrt{2}}\right)$$

$$= \frac{2v}{\sqrt{2}} = \sqrt{2}v$$

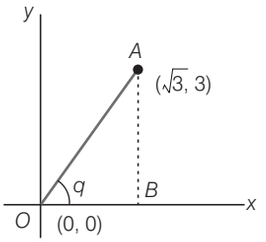
$$\Rightarrow \text{So,} \quad \Delta P_y = m\sqrt{2}v = \sqrt{2}mv$$

26 A particle starting from the origin (0,0) moves in a straight line in the (x, y) plane. Its co-ordinates at a later time are $(\sqrt{3}, 3)$. The path of the particle makes with the x-axis an angle of **[CBSE AIPMT 2007]**

(a) 30° (c) 45° (c) 60° (d) 0°

Ans. *(c)*

Draw the situation as given in questions. *OA* represents the path of the particle starting from origin *O*(0, 0). Draw a perpendicular from point *A* to *x*-axis. Let path of the particle makes an angle θ with the *x*-axis, then



$\tan\theta$ = slope of line *OA*

= path of the particle 1 making angle θ

$$\tan\theta = \frac{3-0}{\sqrt{3}-0} = \sqrt{3}$$

$$\theta = 60°$$

27 For angles of projection of a projectile at angles $(45° - \theta)$ and $(45° + \theta)$, the horizontal ranges described by the projectile are in the ratio of **[CBSE AIPMT 2006]**

(a) 1 : 1 (b) 2 : 3
(c) 1 : 2 (d) 2 : 1

Ans. *(a)*

We know that, horizontal ranges for complementary angles of projection will be same.

The projectiles are projected at angles $(45° - \theta)$ and $(45° + \theta)$ which are complementary to each other i.e. two angles add up to give 90°. Hence, horizontal ranges will be equal. Thus, the required ratio is 1 : 1.

Alternative

Horizontal range of projectile

$$R = \frac{u^2 \sin 2\alpha}{g}$$

For $\alpha = (45° - \theta)$,

$$R_1 = \frac{u^2 \sin 2(45° - \theta)}{g}$$

$$= \frac{u^2 \sin(90° - 2\theta)}{g} = \frac{u^2 \cos 2\theta}{g}$$

For $\alpha = (45° + \theta)$,

$$R_2 = \frac{u^2 \sin 2(45° + \theta)}{g}$$

$$= \frac{u^2 \sin(90° + \theta)}{g}$$

$$= \frac{u^2 \cos 2\theta}{g}$$

Hence, $\frac{R_1}{R_2} = \frac{1}{1}$ or $R_1 : R_2 = 1:1$

28 Two particles are projected with same initial velocities at an angle 30° and 60° with the horizontal. Then, **[CBSE AIPMT 2000]**

(a) their heights will be equal
(b) their ranges will be equal
(c) their time of flights will be equal
(d) their ranges will be different

Ans. *(b)*

(a) Maximum height in case of projectile is given by

$$H = \frac{u^2 \sin^2\theta}{2g} \Rightarrow \frac{H_1}{H_2} = \frac{\sin^2\theta_1}{\sin^2\theta_2}$$

$$= \frac{\sin^2 30°}{\sin^2 60°} = \frac{\left(\frac{1}{2}\right)^2}{\left(\frac{\sqrt{3}}{2}\right)^2} = \frac{1}{3}$$

(b) Range $R = \frac{u^2 \sin 2\theta}{g}$

$$\Rightarrow \quad \frac{R_1}{R_2} = \frac{\sin(2\times 30°)}{\sin(2\times 60°)}$$

$$= \frac{\sin 60°}{\sin 120°} = \frac{\frac{\sqrt{3}}{2}}{\frac{\sqrt{3}}{2}} = 1 \Rightarrow R_1 = R_2$$

(c) Time of flight

$$T = \frac{2u\sin\theta}{g} \Rightarrow \frac{T_1}{T_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

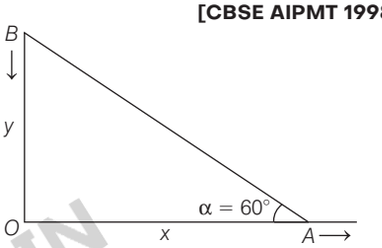
$$= \frac{\sin 30°}{\sin 60°} = \frac{1/2}{\sqrt{3}/2} = \frac{1}{\sqrt{3}}$$

Hence, their horizontal ranges will be equal.

Alternative

In this problem, it is given that two particles are projected at angles 30° and 60° which are complementary angles. We know that horizontal range will be same for complementary angles. Hence, their ranges will be equal.

29 Two particles *A* and *B* are connected by a rigid rod *AB*. The rod slides along perpendicular rails as shown here. The velocity of *A* to the right is 10m/s. What is the velocity of *B* when angle $\alpha = 60°$? **[CBSE AIPMT 1998]**



(a) 9.8 m/s (b) 10 m/s
(c) 5.8 m/s (d) 17.3 m/s

Ans. *(d)*

Let the velocity along *x* and *y*-axes be v_x and v_y respectively.

$$\therefore \qquad v_x = \frac{dx}{dt} \quad \text{and} \quad v_y = \frac{dy}{dt}$$

From figure,

$$\tan\alpha = \frac{y}{x} \Rightarrow y = x\tan\alpha$$

Differentiating Eq. (i), w.r.t. *t*, we get

$$\frac{dy}{dt} = \frac{dx}{dt}\tan\alpha$$

$$\Rightarrow \quad v_y = v_x \tan\alpha$$

Here, $v_x = 10$ m/s, $\alpha = 60°$

$$\therefore \quad v_y = 10\tan 60°$$

$$= 10\sqrt{3} = 17.3 \text{ m/s}$$

30 A bullet is fired from a gun with a speed of 1000 m/s in order to hit a target 100 m away. At what height above the target should the gun be aimed? (The resistance of air is negligible and $g = 10\,\text{m/s}^2$) **[CBSE AIPMT 1995]**

(a) 5 cm (b) 10 cm (c) 15 cm (d) 20 cm

Ans. *(a)*

Horizontal distance of the target is 100 m. Speed of bullet = 1000 m/s

Time taken by bullet to cover the horizontal distance,

$$t = \frac{100}{1000} = \frac{1}{10}\text{ s}$$

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During $\frac{1}{10}$ s, the bullet will fall down vertically due to gravitational acceleration.
Therefore, height above the target, so that the bullet hit the target is

$$h = ut + \frac{1}{2}gt^2 = \left(0 \times \frac{1}{10}\right) + \frac{1}{2} \times 10 \times (0.1)^2$$
$$= 0.05\ \text{m} = 5\ \text{cm}$$

31 The position vector of a particle is $\mathbf{r} = (a\cos\omega t)\,\hat{\mathbf{i}} + (a\sin\omega t)\,\hat{\mathbf{j}}$. The velocity of the particle is **[CBSE AIPMT 1995]**

(a) directed towards the origin
(b) directed away from the origin
(c) parallel to the position vector
(d) perpendicular to the position vector

Ans. *(d)*

Velocity is rate of change of position vector, i.e.,

$$\mathbf{v} = \frac{d\mathbf{r}}{dt}$$

where, $\mathbf{r}$ is the position vector.

$$\therefore\ \mathbf{v} = \frac{d}{dt}[(a\cos\omega t)\hat{\mathbf{i}} + (a\sin\omega t)\hat{\mathbf{j}}]$$
$$= (-a\omega\sin\omega t)\hat{\mathbf{i}} + (a\omega\cos\omega t)\hat{\mathbf{j}}$$
$$= \omega[(-a\sin\omega t)\hat{\mathbf{i}} + (a\cos\omega t)\hat{\mathbf{j}}]$$

Slope of position vector

$$= \frac{a\sin\omega t}{a\cos\omega t} = \tan\omega t$$

and slope of velocity vector $= \dfrac{-a\cos\omega t}{a\sin\omega t}$

$$= -\frac{1}{\tan\omega t}$$

$\therefore$ Velocity is perpendicular to the displacement.

Alternative

Velocity vector and position vector are perpendicular to each other if their scalar product is zero, i.e.

$$\mathbf{v}\cdot\mathbf{r} = 0$$

Now, $\mathbf{v}\cdot\mathbf{r} = [(-a\omega\sin\omega t)\,\hat{\mathrm{i}} + (a\omega\cos\omega t)\,\hat{\mathrm{j}}]$
$[(a\cos\omega t)\,\hat{\mathrm{i}} + (a\sin\omega t)\,\hat{\mathrm{j}}]$

$$= -a^2\omega\sin\omega t\cos\omega t + a^2\omega\sin\omega t\cos\omega t = 0$$

$\Rightarrow$ Velocity vector is perpendicular to position vector.

32 Two bodies of same mass are projected with the same velocity at an angle 30° and 60° respectively. The ratio of their horizontal ranges will be **[CBSE AIPMT 1990]**

(a) 1 : 1 (b) 1 : 2 (c) 1 : 3 (d) 2 : $\sqrt{2}$

Ans. *(a)*

When an object is projected with velocity u making an angle θ with the horizontal direction, then horizontal range will be

$$R_1 = \frac{u^2\sin 2\theta}{g} \quad \ldots(i)$$

when an object is projected with velocity u making an angle $(90° - \theta)$ with the horizontal direction, then horizontal range will be

$$R_2 = \frac{u^2\sin 2(90° - \theta)}{g}$$
$$= \frac{u^2}{g}\sin(180° - 2\theta)$$
$$= \frac{u^2}{g}\sin 2\theta \quad \ldots(ii)$$

From Eqs. (i) and (ii), we note that $R_1 = R_2$

Here, the projection angle is 30° and $60° = (90° - 30°)$, so horizontal range is same for both angles.

$$\therefore \quad \frac{R_1}{R_2} = 1$$

33 The maximum range of a gun of horizontal terrain is 16 km. If $g = 10\,\text{ms}^{-2}$, then muzzle velocity of a shell must be **[CBSE AIPMT 1990]**

(a) 160 ms^{-1} (b) 200 $\sqrt{2}$ ms^{-1}
(c) 400 ms^{-1} (d) 800 ms^{-1}

Ans. *(c)*

Range of projectile is given by

$$R = \frac{u^2\sin 2\theta}{g}$$

For range to be maximum, angle θ should be of 45°.

$$\therefore \quad R_{\max} = \frac{u^2\sin 2\times 45°}{g} = \frac{u^2\sin 90°}{g}$$

or $$R_{\max} = \frac{u^2}{g}$$

Here, $R_{\max} = \dfrac{u^2}{g} = 16\ \text{km} = 16000\ \text{m}$

or $$u = \sqrt{16000\,g} = \sqrt{16000 \times 10}$$
$$= 400\ \text{ms}^{-1}$$

TOPIC 3
Relative Velocity

34 The speed of a swimmer in still water is 20 m/s. The speed of river water is 10 m/s and is flowing due east. If he is standing on the south bank and wishes to cross the river along the shortest path the angle at which he should make his strokes w.r.t. north is given by **[NEET (National) 2019]**

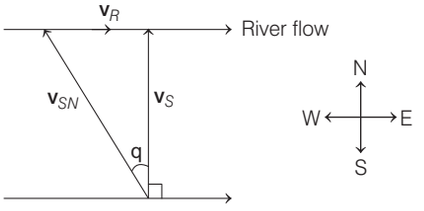
(a) 0º (b) 60° west
(c) 45º west (d) 30º west

Ans. *(d)*

Given,

speed of river, $v_R = 10$ m/s

speed of swimmer in still water and $v_{SN} = 20$ m/s.



For the shortest path to cross the river, he should swim at an angle $(90° + \theta)$ with the stream flow. From the figure above,

$\mathbf{v}_{SN} = \mathbf{v}_R + \mathbf{v}_S$

So, angle θ is given by

$$\sin\theta = \left|\frac{\mathbf{v}_R}{\mathbf{v}_{SN}}\right| = \frac{10}{20} = \frac{1}{2}$$

$\Rightarrow \quad \theta = 30°$

As the river is flowing in East direction, so he should swim towards West.

35 Two particles *A* and *B*, move with constant velocities $\mathbf{v}_1$ and $\mathbf{v}_2$. At the initial moment, their position vectors are $\mathbf{r}_1$ and $\mathbf{r}_2$ respectively. The condition for particles *A* and *B* for their collision is **[CBSE AIPMT 2015]**

(a) $\dfrac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|} = \dfrac{\mathbf{v}_2 - \mathbf{v}_1}{|\mathbf{v}_2 - \mathbf{v}_1|}$
(b) $\mathbf{r}_1\cdot\mathbf{v}_1 = \mathbf{r}_2\cdot\mathbf{v}_2$
(c) $\mathbf{r}_1\times\mathbf{v}_1 = \mathbf{r}_2\times\mathbf{v}_2$
(d) $\mathbf{r}_1 - \mathbf{r}_2 = \mathbf{v}_1 - \mathbf{v}_2$

Ans. *(a)*

For two particles *A* and *B* move with constant velocities $\mathbf{v}_1$ and $\mathbf{v}_2$. Such that two particles to collide, the direction of the relative velocity of one with respect to other should be directed towards the relative position of the other particle.

i.e. $\dfrac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|} \longrightarrow$ direction of relative position of 1 w.r.t. 2.

Similarly, $\dfrac{\mathbf{v}_1 - \mathbf{v}_2}{|\mathbf{v}_1 - \mathbf{v}_2|} \longrightarrow$ direction of velocity of 2 w.r.t. 1.

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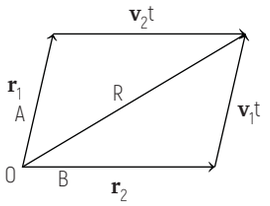
So, for collision of A and B, we get

$$\frac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|} = \frac{\mathbf{v}_2 - \mathbf{v}_1}{|\mathbf{v}_2 - \mathbf{v}_1|}$$

Alternate Method As resultant displacement of a particle,



$$\mathbf{R} = \mathbf{r}_1 - \mathbf{v}_1 t = \mathbf{r}_2 - \mathbf{v}_2 t$$

i.e. $\mathbf{r}_1 - \mathbf{r}_2 = (\mathbf{v}_2 - \mathbf{v}_1)t$

So, $\frac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|} = \frac{(\mathbf{v}_2 - \mathbf{v}_1)t}{|\mathbf{v}_2 - \mathbf{v}_1|t}$

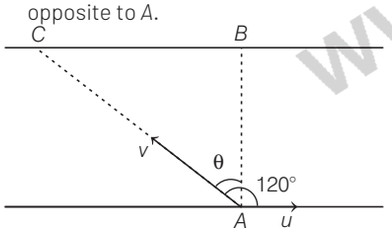
$$\frac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|} = \frac{(\mathbf{v}_2 - \mathbf{v}_1)}{|\mathbf{v}_2 - \mathbf{v}_1|}$$

36 A person swims in a river aiming to reach exactly opposite point on the bank of a river. His speed of swimming is 0.5 m/s at an angle 120° with the direction of flow of water. The speed of water in stream is **[CBSE AIPMT 1999]**

(a) 1.0 m/s (b) 0.5 m/s
(c) 0.25 m/s (d) 0.43 m/s

Ans. *(c)*

Let u be the speed of stream and v be the speed of person started from A. He wants to reach at point B directed opposite to A.



As given, v makes an angle of 120° with direction of flow u, the resultant of v and u is along AB. From figure

$u = v\sin\theta = v\sin 30°$

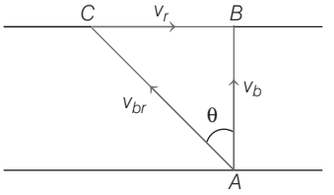
$\therefore \quad u = \frac{v}{2} = \frac{0.5}{2} \qquad (\because v = 0.5 \text{ m/s})$

$= 0.25$ m/s

37 The speed of a boat is 5 km/h in still water. It crosses a river of width 1.0 km along the shortest possible path in 15 min. The velocity of the river water is (in km/h) **[CBSE AIPMT 1998]**

(a) 5 (b) 1 (c) 3 (d) 4

Ans. *(c)*



Let v_r = velocity of river

v_{br} = velocity of boat in still water and

w = width of river

Time taken to cross the river = 15 min

$$= \frac{15}{60}\text{ h} = \frac{1}{4}\text{h}$$

Shortest path is taken when v_b is along AB. In this case,

$$v_{br}^2 = v_r^2 + v_b^2$$

Now, $\quad t = \frac{w}{v_b} = \frac{w}{\sqrt{v_{br}^2 - v_r^2}}$

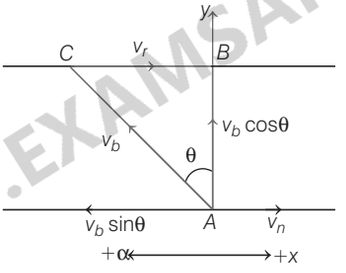
$\therefore \quad \frac{1}{4} = \frac{1}{\sqrt{5^2 - v_r^2}}$

$\Rightarrow \quad 5^2 - v_r^2 = 16$

$\Rightarrow \quad v_r^2 = 25 - 16 = 9$

$\therefore \quad v_r = \sqrt{9} = 3$ km/h

Alternative



$$t = \frac{15}{60} = \frac{1}{4}\lambda \text{ s}$$

$\Rightarrow$ Motion along the Y- axis $t = \frac{y}{v_b\cos\theta}$

$\Rightarrow \quad \frac{1}{4} = \frac{1}{5\cos\theta} \quad \Rightarrow \quad \cos\theta = \frac{4}{5}$

So , $\sin\theta = \frac{3}{5}$

$\Rightarrow$ Motion is along the x-axis.

For the boat to reach at B

$$v_b\sin\theta = v_r \quad \Rightarrow \quad 5 \times \frac{3}{5} = v_r$$

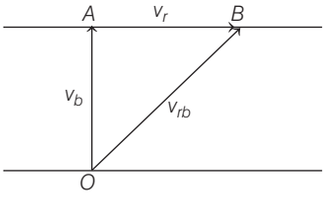
$\Rightarrow \quad v_r = 3$ km/h

38 A boat is sent across a river with a velocity of 8 km h^{-1}. If the resultant velocity of boat is 10 km h^{-1}, then velocity of river is **[CBSE AIPMT 1993]**

(a) 12.8 km h^{-1} (b) 6 km h^{-1}
(c) 8 km h^{-1} (d) 10 km h^{-1}

Ans. *(b)*

The situation is depicted in figure.



Let v_b be the velocity of boat, v_r be the velocity of river and v_{rb} be the resultant velocity of boat.

From figure and concept of relative velocity

$$v_{rb}^2 = v_r^2 + v_b^2$$

$\therefore \quad v_r = \sqrt{v_{rb}^2 - v_b^2}$

$= \sqrt{10^2 - 8^2} = 6$ km h^{-1}

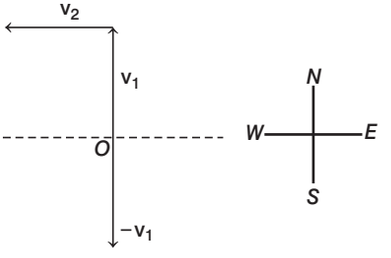
39 A bus is moving on a straight road towards North with a uniform speed of 50 km/h.

If the speed remains unchanged after turning through 90°, the increase in the velocity of bus in the turning process is **[CBSE AIPMT 1989]**

(a) 70.7 km/h along South-West direction
(b) zero
(c) 50 km/h along West
(d) 70.7 km/h along North-West direction

Ans. *(a)*

The situation is depicted in figure.



Here, $\mathbf{v}_1 = 50$ km/h due North

$\mathbf{v}_2 = 50$ km/h due West

From figure it indicates that angle between $\mathbf{v}_1$ and $\mathbf{v}_2$ is 90°.

Now, $-\mathbf{v}_1 = 50$ km/h due South

$\therefore$ Change in velocity

$$= |\mathbf{v}_2 - \mathbf{v}_1| = |\mathbf{v}_2 + (-\mathbf{v}_1)|$$

$$= \sqrt{v_2^2 + v_1^2}$$

$$= \sqrt{50^2 + 50^2}$$

$= 70.7$ km/h

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TOPIC 4
Uniform Circular Motion

40 A particle moving in a circle of radius R with a uniform speed takes a time T to complete one revolution. If this particle were projected with the same speed at an angle θ to the horizontal, the maximum height attained by it equals $4R$. The angle of projection θ is then given by **[NEET 2021]**

(a) $\theta = \cos^{-1}\left(\frac{gT^2}{\pi^2 R}\right)^{\frac{1}{2}}$

(b) $\theta = \cos^{-1}\left(\frac{\pi^2 R}{gT^2}\right)^{\frac{1}{2}}$

(c) $\theta = \sin^{-1}\left(\frac{\pi^2 R}{gT^2}\right)^{\frac{1}{2}}$

(d) $\theta = \sin^{-1}\left(\frac{2gT^2}{\pi^2 R}\right)^{\frac{1}{2}}$

Ans. *(d)*

Given, the radius of the circular path $= R$

The time taken by the particle to complete one revolution $= T$

When the particle is projected with the same speed (by which it is moving in circular orbit) at angle θ to the horizontal, the maximum height attained it is given as

$$H_{max} = \frac{u^2 \sin^2\theta}{2g} \quad ...(i)$$

$$H_{max} = 4R \quad \text{(given)}$$

Also, we know that,
speed of the particle in circular path,

$$u = \frac{2\pi R}{T}$$

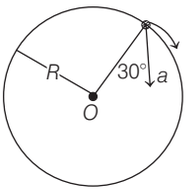
Substituting the values in the Eq. (i), we get

$$4R = \frac{\left(\frac{2\pi R}{T}\right)^2 \sin^2\theta}{2g}$$

$$\Rightarrow \quad \sin\theta = \left(\frac{2gT^2}{\pi^2 R}\right)^{1/2}$$

$$\Rightarrow \quad \theta = \sin^{-1}\left(\frac{2gT^2}{\pi^2 R}\right)^{1/2}$$

41 In the given figure, $a = 15\ \text{m/s}^2$ represents the total acceleration of a particle moving in the clockwise direction in a circle of radius $R = 2.5$ m at a given instant of time. The speed of the particle is **[NEET 2016]**



(a) 4.5 m/s (b) 5.0 m/s
(c) 5.7 m/s (d) 6.2 m/s

Ans. *(c)*

Centripetal acceleration of a particle moving on a circular path is given by

$$a_c = \frac{v^2}{R}$$

In the given figure,

$a_c = a\cos 30° = 15\cos 30°\ \text{m/s}^2$

$$\Rightarrow \quad \frac{v^2}{R} = 15\cos 30°$$

$$\Rightarrow \quad v^2 = R \times 15 \times \frac{\sqrt{3}}{2} = 2.5 \times 15 \times \frac{\sqrt{3}}{2}$$

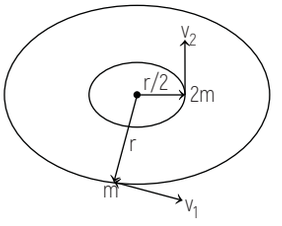
$$\therefore \quad v = 5.7\ \text{m/s}$$

42 Two stones of masses m and $2m$ are whirled in horizontal circles, the heavier one in a radius $\frac{r}{2}$ and the lighter one in radius r. The tangential speed of lighter stone is n times that of the value of heavier stone when they experience same centripetal forces. The value of n is **[CBSE AIPMT 2015]**

(a) 2 (b) 3 (c) 4 (d) 1

Ans. *(a)*

Given, that two stones of masses m and $2m$ are whirled in horizontal circles, the heavier one in a radius $\frac{r}{2}$ and lighter one in radius r as shown in figure.



As, lighter stone is n times that of the value of heavier stone when they experience same centripetal forces, we get

$$(F_c)_{heavier} = (F_c)_{lighter}$$

$$\Rightarrow \quad \frac{2m(v)^2}{(r/2)} = \frac{m(nv)^2}{r}$$

$$\Rightarrow \quad n^2 = 4 \Rightarrow n = 2$$

43 A particle moves in a circle of radius 5 cm with constant speed and time period 0.2πs. The acceleration of the particle is **[CBSE AIPMT 2011]**

(a) 25 m/s^2 (b) 36 m/s^2
(c) 5 m/s^2 (d) 15 m/s^2

Ans. *(c)*

Given, $r = 5\,\text{cm} = 5 \times 10^{-2}$ m

$T = 0.2\ \pi$s

We know that acceleration is given by

$$a = r\omega^2 = \frac{4\pi^2}{T^2} r = \frac{4 \times \pi^2 \times 5 \times 10^{-2}}{(0.2\ \pi)^2}$$

$$= 5\ \text{m/s}^2$$

44 A car runs at a constant speed on a circular track of radius 100 m, taking 62.8 s for every circular lap. The average velocity and average speed for each circular lap respectively is **[CBSE AIPMT 2006]**

(a) 0, 0 (b) 0, 10 m/s
(c) 10 m/s, 10 m/s (d) 10 m/s, 0

Ans. *(b)*

Concept Average velocity is defined as the ratio of displacement to time taken while the average speed of a particle in a given interval of time is defined as the ratio of distance travelled to the time taken. On a circular path in completing one turn, the distance travelled is $2\pi r$ while displacement is zero.

Hence, average velocity $= \frac{\text{Displacement}}{\text{Time - interval}}$

$$= \frac{0}{t} = 0$$

Average speed $= \frac{\text{Distance}}{\text{Time - interval}}$

$$= \frac{2\pi r}{t} = \frac{2 \times 3.14 \times 100}{62.8}$$

$$= 10\ \text{ms}^{-1}$$

45 A stone tied to the end of a string of 1 m long is whirled in a horizontal circle with a constant speed. If the stone makes 22 revolutions in 44 s, what is the magnitude and direction of acceleration of the stone? **[CBSE AIPMT 2005]**

(a) $\frac{\pi^2}{4}\ \text{ms}^{-2}$ and direction along the radius towards the centre

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(b) π^2 ms^{-2} and direction along the radius away from centre
(c) π^2 ms^{-2} and direction along the radius towards the centre
(d) π^2 ms^{-2} and direction along the tangent to the circle

Ans. *(c)*

Since, speed is constant throughout the motion, so, it is a uniform circular motion. Therefore, its radial acceleration is given by

$$a_r = r\omega^2 = r\left(\frac{2\pi n}{t}\right)^2 = r \times \frac{4\pi^2 n^2}{t^2} = \frac{1 \times 4 \times \pi^2 \times (22)^2}{(44)^2}$$

$= \pi^2$ m/s^2

This acceleration is directed along radius of circle.

46 The circular motion of a particle with constant speed is **[CBSE AIPMT 2005]**

(a) simple harmonic but not periodic
(b) periodic and simple harmonic
(c) neither periodic nor simple harmonic
(d) periodic but not simple harmonic

Ans. *(d)*

In a circular motion, particle repeats its motion after equal intervals of time. So, particle moving on a circular path is periodic but not simple harmonic as it does not execute to and fro motion about a fixed point.

47 A particle moves along a circle of radius $\left(\frac{20}{\pi}\right)$ m with constant tangential acceleration. If the velocity of the particle is 80 m/s at the end of the second revolution after motion has begin, the tangential acceleration is **[CBSE AIPMT 2003]**

(a) 160 π m/s^2 (b) 40 m/s^2
(c) 40 π m/s^2 (d) 640 π m/s^2

Ans. *(b)*

The tangential acceleration is given by

$$a_T = r\alpha \quad \text{...(i)}$$

From 2nd equation of motion for rotational motion,

$$\omega^2 = \omega_0^2 + 2\alpha\theta$$

Here, initial angular velocity, $\omega_0 = 0$,
Final angular velocity,

$$\omega = \frac{v}{r} = \frac{80}{20/\pi} = 4\pi \text{ rad/s}$$

$$\theta = 2 \times 2\pi \text{ rad}$$

So, angular acceleration

$$\alpha = \frac{\omega^2}{2\theta} = \frac{(4\pi)^2}{2 \times (2 \times 2\pi)} = \frac{16\pi^2}{8\pi} = 2\pi$$

Hence, from Eq. (i), we have

$$a_T = r\alpha = \frac{20}{\pi} \times 2\pi = 40 \text{ m/s}^2$$

Alternative

Initial velocity, $u = 0$
Final velocity, $v = 80$ m/s
Radius of circle $r = \left(\frac{20}{11}\right)$ m
Distance travelled, $S = 2 \times (2\pi r)$

$$= 2 \times \left(2\pi \times \frac{20}{\pi}\right) = 80 \text{ m}$$

Now, by applying third equation of motion,

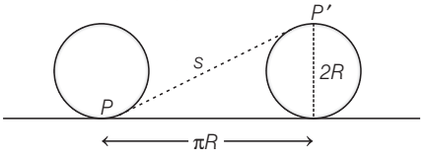
$$v^2 = u^2 + 2as$$
$$(80)^2 = 0 + 2 \times a_t \times 80$$
$$a_t = 40 \text{ m/s}^2$$

48 *P* is the point of contact of a wheel and the ground. The radius of wheel is 1m. The wheel rolls on the ground without slipping. The displacement of point *P* when wheel completes half rotation is **[CBSE AIPMT 2002]**

(a) 2 m (b) $\sqrt{\pi^2 + 4}$ m
(c) π m (d) $\sqrt{\pi^2 + 2}$ m

Ans. *(b)*

When the wheel rolls on the ground without slipping and completes half rotation, point *P* takes new position as *P*′ as shown in figure.



Horizontal displacement, $x = \pi R$
Vertical displacement, $y = 2R$
Thus, displacement of the point *P* when wheel completes half rotation,

$$s = \sqrt{x^2 + y^2} = \sqrt{(\pi R)^2 + (2R)^2} = \sqrt{\pi^2 R^2 + 4R^2}$$

but $R = 1$ m (given)

$$\therefore \quad s = \sqrt{\pi^2 (1)^2 + 4(1)^2} = \sqrt{\pi^2 + 4} \text{ m}$$

49 A particle of mass *M* is revolving along a circle of radius *R* and another particle of mass *m* is revolving in a circle of radius *r*. If time periods of both particles are same, then the ratio of their angular velocities is **[CBSE AIPMT 2001]**

(a) 1 (b) $\frac{R}{r}$
(c) $\frac{r}{R}$ (d) $\sqrt{\frac{R}{r}}$

Ans. *(a)*

Angular velocity of particle is given by

$$\omega = \frac{2\pi}{T}$$

or $$\omega \propto \frac{1}{T}$$

[T = time period of the particle]

It simply implies that ω does not depend on mass of the body and radius of the circle.

$$\therefore \quad \frac{\omega_1}{\omega_2} = \frac{T_2}{T_1}$$

but given time period is same, i.e. $T_1 = T_2$

Hence, $$\frac{\omega_1}{\omega_2} = \frac{1}{1}$$

50 What is the linear velocity, if angular velocity vector $\omega = 3\hat{i} - 4\hat{j} + \hat{k}$ and position vector $\mathbf{r} = 5\hat{i} - 6\hat{j} + 6\hat{k}$? **[CBSE AIPMT 1999]**

(a) $6\hat{i} + 2\hat{j} - 3\hat{k}$
(b) $-18\hat{i} - 13\hat{j} + 2\hat{k}$
(c) $18\hat{i} + 13\hat{k} - 2\hat{k}$
(d) $6\hat{i} - 2\hat{j} + 8\hat{k}$

Ans. *(b)*

The relation between linear velocity $\mathbf{v}$, angular velocity ω and position vector $\mathbf{r}$ is given by

$$\mathbf{v} = \omega \times \mathbf{r} = (3\hat{i} - 4\hat{j} + \hat{k}) \times (5\hat{i} - 6\hat{j} + 6\hat{k})$$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & -4 & 1 \\ 5 & -6 & 6 \end{vmatrix}$$

$$= \hat{i}\begin{vmatrix} -4 & 1 \\ -6 & 6 \end{vmatrix} - \hat{j}\begin{vmatrix} 3 & 1 \\ 5 & 6 \end{vmatrix} + \hat{k}\begin{vmatrix} 3 & -4 \\ 5 & -6 \end{vmatrix}$$

$$= (-24 + 6)\hat{i} - (18 - 5)\hat{j} + (-18 + 20)\hat{k}$$

$$= -18\hat{i} - 13\hat{j} + 2\hat{k}$$

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Alternative

$$\mathbf{v} = \boldsymbol{\omega} \times \mathbf{r}$$
$$= (3\hat{\mathbf{i}} - 4\hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (5\hat{\mathbf{i}} - 6\hat{\mathbf{j}} + 6\hat{\mathbf{k}})$$
$$= (3\times 5)(\hat{\mathbf{i}} \times \hat{\mathbf{i}}) + [3\times(-6)](\hat{\mathbf{i}} \times \hat{\mathbf{j}}) + (3\times 6)(\hat{\mathbf{i}} \times \hat{\mathbf{k}}) + (-4\times 5)(\hat{\mathbf{j}} \times \hat{\mathbf{i}}) + (-4\times -6)(\hat{\mathbf{j}} \times \hat{\mathbf{j}}) + (-4\times 6)(\hat{\mathbf{j}} \times \hat{\mathbf{k}}) + (1\times 5)(\hat{\mathbf{k}} \times \hat{\mathbf{i}}) + (1\times -6)(\hat{\mathbf{k}} \times \hat{\mathbf{j}}) + (1\times 6)(\hat{\mathbf{k}} \times \hat{\mathbf{k}})$$

Use $\hat{\mathbf{i}} \times \hat{\mathbf{j}} = -\hat{\mathbf{j}} \times \hat{\mathbf{i}} = \hat{\mathbf{k}}$

$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = -\hat{\mathbf{k}} \times \hat{\mathbf{j}} = \hat{\mathbf{i}}$

and $\hat{\mathbf{k}} \times \hat{\mathbf{i}} = -\hat{\mathbf{i}} \times \hat{\mathbf{k}} = \hat{\mathbf{j}}$

Thus, $\mathbf{v} = 0 + (-18)(\hat{\mathbf{k}}) + (18)(-\hat{\mathbf{j}}) + (-20)(-\hat{\mathbf{k}}) + 0 + (-24)(\hat{\mathbf{i}}) + (5)(\hat{\mathbf{j}}) + (-6)(-\hat{\mathbf{i}}) + 0$

$= -18\hat{\mathbf{k}} - 18\hat{\mathbf{j}} + 20\hat{\mathbf{k}} - 24\hat{\mathbf{i}} + 5\hat{\mathbf{j}} + 6\hat{\mathbf{i}}$

$= -18\hat{\mathbf{i}} - 13\hat{\mathbf{j}} + 2\hat{\mathbf{k}}$

51 A body is whirled in a horizontal circle of radius 20 cm. It has an angular velocity of 10 rad/s. What is its linear velocity at any point on circular path? **[CBSE AIPMT 1996]**

(a) $\sqrt{2}$ m/s
(b) 2 m/s
(c) 10 m/s
(d) 20 m/s

Ans. ***(b)***

Linear speed = radius × angular speed

or $v = r\omega$

Here, $r = 20\,\text{cm} = 0.20\ \text{m}$

$\omega = 10\ \text{rad/s}$

$\therefore \quad v = 0.20 \times 10$

$\Rightarrow \quad v = 2\ \text{m/s}$

52 When milk is churned, cream gets separated due to **[CBSE AIPMT 1991]**

(a) centripetal force
(b) centrifugal force
(c) frictional force
(d) gravitational force

Ans. ***(b)***

By the concept of centrifugal force cream is separated from milk. A mass m of milk revolving at a distance r from the axis of rotation of the centrifuge requires a centripetal force $mr\omega^2$, where ω is the angular speed of the centrifuge. If in place of this mass of milk, lighter particles of mass (cream) $m'(m' < m)$ are present, then the centripetal force $(mr\omega^2)$ on the milk will be greater than the centripetal force $(m'r\omega^2)$ on the cream.

As a result, cream move towards the axis of rotation under the effect of the net force $(m - m')\,r\omega^2$. When the centrifuge is stopped, the cream is found at the top and milk at the bottom.

53 An electric fan has blades of length 30 cm measured from the axis of rotation. If the fan is rotating at 120 rev/min, the acceleration of a point on the tip of the blade is **[CBSE AIPMT 1990]**

(a) 1600 ms^{-2} (b) 47.4 ms^{-2}
(c) 23.7 ms^{-2} (d) 50.55 ms^{-2}

Ans. ***(b)***

Centripetal acceleration of rotating body is given by

$$a_c = \frac{v^2}{r} = \frac{r^2\omega^2}{r} = r\omega^2 \qquad (\text{as } v = r\omega)$$

Where, ω is angular frequency, but $\omega = 2\pi\nu$, where ν is frequency of rotation.

$\therefore \quad a_c = r(2\pi\nu)^2 = r4\pi^2\nu^2$

Here, $r = 30\ \text{cm} = 30 \times 10^{-2}\ \text{m} = 0.30\ \text{m}$

$$v = 120\ \text{rev/m} = \frac{120}{60}\ \text{rev/s} = 2\ \text{rev/s}$$

$\therefore \quad a_c = (0.30 \times 4 \times 3.14 \times 3.14 \times 2 \times 2)$

$= 47.4\,\text{ms}^{-2}$

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04

Laws of Motion

TOPIC 1

Newtons Laws of Motion and Conservation of Momentum

01 A ball of mass 0.15 kg is dropped from a height 10 m, strikes the ground and rebounds to the same height. The magnitude of impulse imparted to the ball is nearly ($g = 10\ m/s^2$) **[NEET 2021]**

(a) 0 (b) 4.2 kg-m/s

(c) 2.1 kg-m/s (d) 1.4 kg-m/s

Ans. *(b)*

Given, the mass of the ball dropped from the height, $m = 0.15$ kg

The height from the ball dropped,

$$h = 10\ m$$

We know that,

$$|\text{Impulse}| = m|\Delta\bar{v}|$$

where, $\Delta\bar{v} = v_2 - v_1$

Here, v_2 is velocity reaches to the same height,

v_1 is velocity just before striking to the ground.

For case (1), ball dropped from the 10m height and strikes to the ground.

Now, the velocity of the ball just before striking to the ground is

$$v_1 = -\sqrt{2gh}$$

$$\Rightarrow\ v_1 = -\sqrt{2(10)(10)}$$

$$\Rightarrow\ v_1 = -10\sqrt{2}\ m/s$$

For case (2), ball rebounds to the same height.

The velocity with which the ball just reaches to the same height,

$$v_2 = \sqrt{2gh}$$

$$\Rightarrow\ v_2 = \sqrt{2(10)(10)}$$

$$\Rightarrow\ v_2 = 10\sqrt{2}\ m/s$$

Now, magnitude of the impulse imparted to the ball,

$$|\text{Impulse}| = m|\Delta\bar{v}|$$

$$= 0.15\ |10\sqrt{2} - (-10\sqrt{2})|$$

$$= 0.15|2 \times 10\sqrt{2}|$$

$$= 4.2\ \text{kg-m/s}$$

02 A truck is stationary and has a bob suspended by a light string, in a frame attached to the truck. The truck, suddenly moves to the right with an acceleration of a. The pendulum will tilt **[NEET (Odisha) 2020]**

(a) to the left and the angle of inclination of the pendulum with the vertical is $\sin^{-1}\left(\frac{g}{a}\right)$

(b) to the left and angle of inclination of the pendulum with the vertical is $\tan^{-1}\left(\frac{a}{g}\right)$

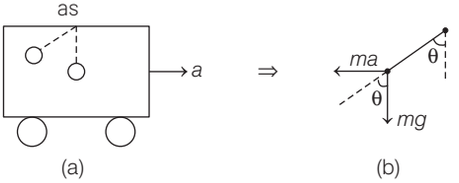
(c) to the left and angle of inclination of the pendulum with the vertical is $\sin^{-1}\left(\frac{a}{g}\right)$

(d) to the left and angle of inclination of the pendulum with the vertical is $\tan^{-1}\left(\frac{g}{a}\right)$

Ans. *(b)*

As the truck move to the right, so the bob will move to the left due to inertia of rest with acceleration a.

Thus, the given situation can be drawn as



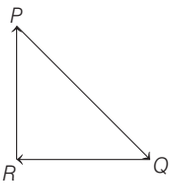
(a) (b)

From the above diagram (b) as the string moves by an angle of θ with the vertical then the tangent angle is

$$\tan\theta = \frac{ma}{mg} \Rightarrow \theta = \tan^{-1}\left(\frac{a}{g}\right)$$

03 A particle moving with velocity $\mathbf{v}$ is acted by three forces shown by the vector triangle PQR.

The velocity of the particle will **[NEET (National) 2019]**



(a) decrease

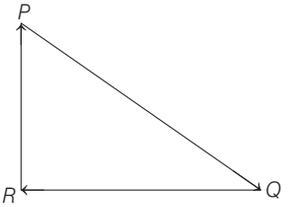
(b) remain constant

(c) change according to the smallest force QR

(d) increase

Ans. *(b)*

As the three forces are represented by three sides of a triangle taken in order, then they will be in equilibrium.



$$\Rightarrow \mathbf{F}_{net} = \mathbf{F}_{PQ} + \mathbf{F}_{QR} + \mathbf{F}_{RP} = 0$$

$$\mathbf{F}_{net} = m \times \mathbf{a} = m\frac{d\mathbf{v}}{dt} = 0 \Rightarrow \frac{dv}{dt} = 0$$

or $\mathbf{v} = \text{constant}$

So, the velocity of particle remain constant.

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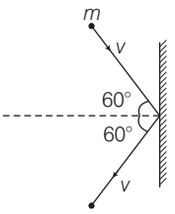
04 A rigid ball of mass m strikes a rigid wall at 60° and gets reflected without loss of speed as shown in the figure. The value of impulse imparted by the wall on the ball will be **[NEET 2016]**



(a) mv (b) $2mv$ (c) $mv/2$ (d) $mv/3$

Ans. *(a)*

As we know that, impulse is imparted due to change in perpendicular components of momentum of ball.

$$J = \Delta p = mv_f - mv_i$$
$$= mv\cos 60° - (-mv\cos 60°)$$
$$= 2mv\cos 60° = 2mv \times \frac{1}{2} = mv$$

05 A bullet of mass 10 g moving horizontal with a velocity of 400 m/s strikes a wood block of mass 2 kg which is suspended by light inextensible string of length 5 m. As result, the centre of gravity of the block found to rise a vertical distance of 10 cm. The speed of the bullet after it emerges of horizontally from the block will be **[NEET 2016]**

(a) 100 m/s (b) 80 m/s
(c) 120 m/s (d) 160 m/s

Ans. *(c)*

According to the law of conservation of momentum, $p_i = p_f$

$$\Rightarrow \quad (0.01)\times 400 + 0 = 2v + (0.01)v' \quad ...(i)$$

Also velocity v of the block just after the collision is

$$v = \sqrt{2gh} = \sqrt{2\times 10\times 0.1} = \sqrt{2} \quad ...(ii)$$

$\Rightarrow$ From Eqs. (i) and (ii), we have

$$v' \approx 120 \text{ m/s}$$

06 The force F acting on a particle of mass m is indicated by the force-time graph shown below. The change in momentum of the particle over the time interval from 0 to 8 s is **[CBSE AIPMT 2014]**

(a) 24 N-s (b) 20 N-s (c) 12 N-s (d) 6 N-s

Ans. *(c)*

The area under F-t graph gives change in momentum.

For 0 to 2 s, $\Delta p_1 = \frac{1}{2}\times 2\times 6$

$$= 6 \text{ kg-m/s}$$

For 2 to 4 s, $\Delta p_2 = 2\times -3 = -6$ kg-m/s

For 4 to 8 s, $\Delta p_3 = 4\times 3 = 12$ kg-m/s

So, total change in momentum for 0 to 8 s

$$\Delta p_{net} = \Delta p_1 + \Delta p_2 + \Delta p_3$$
$$= (+6 - 6 + 12)$$
$$= 12 \text{ kg-m/s} = 12 \text{ N-s}$$

NOTE

Graphs on negative axis gives – ve momentum.

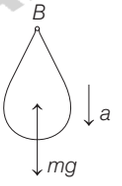
07 A balloon with mass m is descending down with an acceleration a (where, $a < g$). How much mass should be removed from it so that it starts moving up with an acceleration a?

[CBSE AIPMT 2014]

(a) $\frac{2ma}{g+a}$ (b) $\frac{2ma}{g-a}$ (c) $\frac{ma}{g+a}$ (d) $\frac{ma}{g-a}$

Ans. *(a)*

When, the balloon is descending down with acceleration a



So, from free body diagram

$$mg - B = m\times a \quad ...(i)$$

$[B \rightarrow$ Buoyant force$]$

Here, we should assume that while removing same mass the volume of balloon and hence, buoyant force will not change.

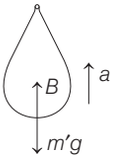
Let the new mass of the balloon be m'.

So, mass removed $(m - m')$

So, $B - m'g = m'\times a \quad ...(ii)$

Solving Eqs. (i) and (ii),

$$mg - B = m\times a$$
$$B - m'g = m'\times a$$
$$mg - m'g = ma + m'a$$
$$(mg - ma) = m'(g + a)$$
$$\Rightarrow \quad m(g-a) = m'(g+a)$$
$$m' = \frac{m(g-a)}{g+a}$$



So, mass removed $= m - m'$

$$\Rightarrow \quad m\left[1 - \frac{(g-a)}{(g+a)}\right]$$
$$= m\left[\frac{(g+a)-(g-a)}{(g+a)}\right]$$
$$\Rightarrow \quad m\left[\frac{g+a-g+a}{g+a}\right] \Rightarrow \Delta m = \frac{2ma}{g+a}$$

08 An explosion breaks a rock into three parts in a horizontal plane. Two of them go off at right angles to each other. The first part of mass 1 kg moves with a speed of 12 ms^{-1} and the second part of mass 2 kg moves with 8 ms^{-1} speed. If the third part flies off with 4 ms^{-1} speed, then its mass is **[NEET 2013]**

(a) 3 kg (b) 5 kg
(c) 7 kg (d) 17 kg

Ans. *(b)*

Concept Momentum is conserved before and after collision.

We have, $\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_3 = 0 \quad [\because p = mv]$

$$\therefore \quad 1\times 12\mathbf{i} + 2\times 8\mathbf{j} + \mathbf{p}_3 = 0$$
$$\Rightarrow \quad 12\hat{\mathbf{i}} + 16\hat{\mathbf{j}} + \mathbf{p}_3 = 0$$
$$\Rightarrow \quad \mathbf{p}_3 = -(12\mathbf{i} + 16\mathbf{j})$$
$$\therefore \quad \mathbf{p}_3 = \sqrt{(12)^2 + (16)^2}$$
$$= \sqrt{144 + 256}$$
$$= 20 \text{ kg-m/s}$$

Now, $\mathbf{p}_3 = m_3 v_3$

$$\Rightarrow \quad m_3 = \frac{\mathbf{p}_3}{v_3} = \frac{20}{4} = 5 \text{ kg}$$

09 Two spheres A and B of masses m_1 and m_2 respectively collide. A is at rest initially and B is moving with velocity v along x-axis. After collision, B has a velocity $\frac{v}{2}$ in a direction perpendicular to the original direction. The mass A moves after collision in the direction **[CBSE AIPMT 2012]**

(a) same as that of B
(b) opposite to that of B

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(c) $\theta = \tan^{-1}\left(\frac{1}{2}\right)$ to the x-axis

(d) $\theta = \tan^{-1}\left(\frac{-1}{2}\right)$ to the x-axis

Ans. *(c)*

Here, $\mathbf{p}_i = m_2 v\hat{\mathbf{i}} + m_1 \times 0$

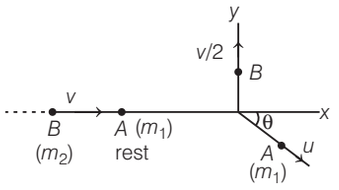
$$\mathbf{p}_f = m_2 \frac{v}{2}\hat{\mathbf{j}} + m_1 \times \mathbf{v}_1$$

Law of conservation of momentum

$$\mathbf{p}_i = \mathbf{p}_f$$

$$m_2 v\hat{\mathbf{i}} = m_2 \frac{v}{2}\hat{\mathbf{j}} + m_1 \times \mathbf{v}_1$$

$$\mathbf{v}_1 = \frac{m_2}{m_1} v\hat{\mathbf{i}} + \frac{m_2}{m_1}\frac{v}{2}\hat{\mathbf{j}}$$



From this equation, we can find

$\tan\theta = \frac{y}{x} = \frac{1}{2}, \theta = \tan^{-1}\left(\frac{1}{2}\right)$ to the x-axis.

10 A man of 50 kg mass is standing in a gravity free space at a height of 10 m above the floor. He throws a stone of 0.5 kg mass downwards with a speed 2 ms^{-1}. When the stone reaches the floor, the distance of the man above the floor will be **[CBSE AIPMT 2010]**

(a) 9.9 m (b) 10.1 m (c) 10 m (d) 20 m

Ans. *(b)*

As, mr = constant

$$m_1 r_1 = m_2 r_2$$

$$\Rightarrow \quad r_2 = \frac{m_1 r_1}{m_2} = \frac{0.5 \times 10}{50} = 0.1$$

So, distance travelled by the man will be

$$10 + 0.1 = 10.1\,\text{m}$$

11 A body, under the action of a force $\mathbf{F} = 6\hat{\mathbf{i}} - 8\hat{\mathbf{j}} + 10\hat{\mathbf{k}}$, acquires an acceleration of 1 ms^{-2}. The mass of this body must be **[CBSE AIPMT 2009]**

(a) $2\sqrt{10}$ kg (b) 10 kg
(c) 20 kg (d) $10\sqrt{2}$ kg

Ans. *(d)*

Here, $\mathbf{F} = 6\hat{\mathbf{i}} - 8\hat{\mathbf{j}} + 10\hat{\mathbf{k}}$

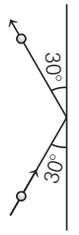
$$|F| = \sqrt{36 + 64 + 100} = 10\sqrt{2}\,\text{N}$$

$$a = 1\,\text{ms}^{-2}$$

$$\therefore \quad m = \frac{10\sqrt{2}}{1} \qquad [\because F = ma]$$

$$= 10\sqrt{2}\,\text{kg}$$

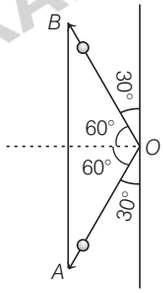
12 A 0.5 kg ball moving with a speed of 12 m/s strikes a hard wall at an angle of 30° with the wall. It is reflected with the same speed and at the same angle. If the ball is in contact with the wall for 0.25 s, the average force acting on the wall is **[CBSE AIPMT 2006]**



(a) 48 N (b) 24 N (c) 12 N (d) 96 N

Ans. *(b)*

The vector **OA** represents the momentum of the object before the collision, and the vector **OB** that after the collision. The vector **AB** represents the change in momentum of the object $\Delta\mathbf{p}$.



As the magnitudes of **OA** and **OB** are equal, the components of **OA** and **OB** along the wall are equal and in the same direction, while those perpendicular to the wall are equal and opposite. Thus, the change in momentum is only due to the change in direction of the perpendicular components.

Hence,

$\Delta p = OB\sin 30° - (-OA\sin 30°)$

$= mv\sin 30° - (-mv\sin 30°)$

$= 2mv\sin 30°$

Its time rate will appear in the form of average force acting on the wall.

$\therefore \quad F \times t = 2mv\sin 30°$ or

$$F = \frac{2mv\sin 30°}{t}$$

Given, $m = 0.5$ kg, $v = 12$ m/s, $t = 0.25$ s

$\theta = 30°$

Hence, $F = \frac{2 \times 0.5 \times 12\sin 30°}{0.25} = 24$ N

13 A block of mass m is placed on a smooth wedge of inclination θ. The whole system is accelerated horizontally, so that the block does not slip on the wedge. The force exerted by the wedge on the block (g is acceleration due to gravity) will be **[CBSE AIPMT 2004]**

(a) $mg\cos\theta$ (b) $mg\sin\theta$
(c) mg (d) $\frac{mg\sin\theta}{\cos\theta}$

Ans. *(d)*

Let an acceleration to the wedge be given towards left, then the block (being in non-inertial frame) has a pseudo acceleration to the right because of which the block is not slipping

$$\therefore \quad mg\sin\theta = a_{\text{pseudo}}\cos\theta$$

$$\Rightarrow \quad a_{\text{pseudo}} = \frac{mg\sin\theta}{\cos\theta}$$

14 An object of mass 3 kg is at rest. If a force $\mathbf{F} = (6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})$ N is applied on the object, then the velocity of the object at $t = 3$ s is **[CBSE AIPMT 2002]**

(a) $18\hat{\mathbf{i}} + 3\hat{\mathbf{j}}$ (b) $18\hat{\mathbf{i}} + 6\hat{\mathbf{j}}$
(c) $3\hat{\mathbf{i}} + 18\hat{\mathbf{j}}$ (d) $18\hat{\mathbf{i}} + 4\hat{\mathbf{j}}$

Ans. *(b)*

According to Newton's 2nd law, force applied on an object is equal to rate of change of momentum.

i.e. $$\mathbf{F} = \frac{d\mathbf{p}}{dt}$$

or $$\mathbf{F} = m\frac{dv}{dt} \qquad \ldots(i)$$

Given, $m = 3$ kg, $t = 3$ s, $\mathbf{F} = (6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})$ N

Substituting these values in Eq. (i), we get

$$(6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}}) = 3\frac{d\mathbf{v}}{dt}$$

or $$d\mathbf{v} = \frac{1}{3}(6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})\,dt$$

Now, taking integration of both sides, we get

$$\int d\mathbf{v} = \int_0^t \frac{1}{3}(6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})\,dt$$

$$\mathbf{v} = \frac{1}{3}\int_0^t (6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})\,dt$$

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but $t = 3$ s (given)

$\therefore \quad \mathbf{v} = \frac{1}{3}\int_0^3 (6t^2\hat{\mathbf{i}} + 4t\hat{\mathbf{j}})\,dt$

or $\mathbf{v} = \frac{1}{3}\left[\frac{6t^3}{3}\hat{\mathbf{i}} + \frac{4t^2}{2}\hat{\mathbf{j}}\right]_0^3$

or $\mathbf{v} = \frac{1}{3}[2(3)^3\hat{\mathbf{i}} + 2(3)^2\hat{\mathbf{j}}]$

or $\mathbf{v} = \frac{1}{3}[54\hat{\mathbf{i}} + 18\hat{\mathbf{j}}]$

or $\mathbf{v} = 18\hat{\mathbf{i}} + 6\hat{\mathbf{j}}$

15 A player takes 0.1 s in catching a ball of mass 150 g moving with velocity of 20 m/s. The force imparted by the ball on the hands of the player is **[CBSE AIPMT 2001]**

(a) 0.3 N (b) 3 N (c) 30 N (d) 300 N

Ans. *(c)*

Force imparted = rate of change of momentum

$F = \frac{\Delta p}{\Delta t}$ or $F = \frac{p_1 - p_2}{\Delta t}$ or $F = \frac{m(v_1 - v_2)}{\Delta t}$

Here, mass of body $m = 150$ g $= 0.150$ kg,

$v_1 = 20$ m/s,

$v_2 = 0$

Time taken, $\Delta t = 0.1$ s

$\therefore \quad F = \frac{0.150 \times (20 - 0)}{0.1} = 30$ N

16 1 kg body explodes into three fragments. The ratio of their masses is 1 : 1 : 3. The fragments of same mass move perpendicular to each other with speeds 30 m/s, while the heavier part remains in the initial direction. The speed of heavier part is **[CBSE AIPMT 2001]**

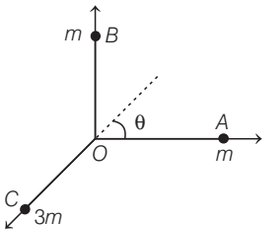
(a) $\frac{10}{\sqrt{2}}$ m/s (b) $10\sqrt{2}$ m/s

(c) $20\sqrt{2}$ m/s (d) $30\sqrt{2}$ m/s

Ans. *(b)*

Concept Apply conservation of momentum with direction.

Let u be the velocity and θ the direction of the third piece as shown.



Equating the momentum of the system along OA and OB to zero, we get

$m \times 30 - 3m \times v\cos\theta = 0$ ...(i)

and $m \times 30 - 3m \times v\sin\theta = 0$ ...(ii)

From Eqs. (i) and (ii), we get

$3mv\cos\theta = 3mv\sin\theta$ or $\cos\theta = \sin\theta$

$\therefore \quad \theta = 45°$

Thus, $\angle AOC = \angle BOC$

$= 180° - 45° = 135°$

Putting the value of θ in Eq. (i), we get

$30m = 3mv\cos 45° = \frac{3mv}{\sqrt{2}}$

$\therefore \quad v = 10\sqrt{2}$ m/s

The third piece will go with a velocity of $10\sqrt{2}$ m/s in a direction making an angle of 135° with either piece.

Alternative

The square of momentum of third piece is equal to sum of squares of momentum first and second pieces.

$p_3^2 = p_1^2 + p_2^2$

or $p_3 = \sqrt{p_1^2 + p_2^2}$

or $3mv_3 = \sqrt{(m \times 30)^2 + (m \times 30)^2}$

or $v_3 = \frac{30\sqrt{2}}{3} = 10\sqrt{2}$ m/s

17 A particle of mass 1 kg is thrown vertically upwards with speed 100 m/s. After 5 s, it explodes into two parts. One part of mass 400 g comes back with speed 25 m/s, what is the speed of other part just after explosion? **[CBSE AIPMT 2000]**

(a) 100 m/s upwards

(b) 600 m/s upwards

(c) 100 m/s downwards

(d) 300 m/s upwards

Ans. *(a)*

According to 1st equation of motion, velocity of particle after 5 s

$v = u - gt$

$v = 100 - 10 \times 5$

$= 100 - 50 = 50$ m/s (upwards)

Applying conservation of linear momentum gives

$Mv = m_1v_1 + m_2v_2$ ...(i)

Taking upward direction positive, the velocity v_1 will be negative.

$\therefore \quad v_1 = -25$ m/s, $v = 50$ m/s

Also, $M = 1$ kg, $m_1 = 400$ g $= 0.4$ kg

and $m_2 = (M - m_1) = 1 - 0.4 = 0.6$ kg

Thus, Eq. (i) becomes,

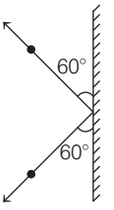
$1 \times 50 = 0.4 \times (-25) + 0.6\,v_2$

or $50 = -10 + 0.6\,v_2$

or $0.6\,v_2 = 60$ or $v_2 = \frac{60}{0.6} = 100$ m/s

As v_2 is positive, therefore the other part will move upwards with a velocity of 100 m/s.

18 A ball of mass 3 kg moving with a speed of 100 m/s, strikes a wall at an angle 60° (as shown in figure). The ball rebounds at the same speed and remains in contact with the wall for 0.2 s, the force exerted by the ball on the wall is **[CBSE AIPMT 2000]**



(a) $1500\sqrt{3}$ N (b) 1500 N

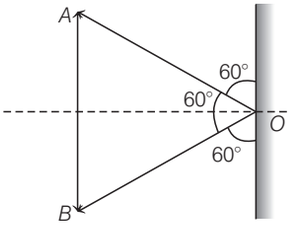
(c) $300\sqrt{3}$ N (d) 300 N

Ans. *(a)*

Concept Apply 2nd law of motion i.e., rate of change of momentum is equal to force applied.

The vector **OA** represents the momentum of the wall, before the collision and the vector **OB** that after the collision. The vector **AB** represents the change in momentum of the ball $\Delta\mathbf{P}$.

As, the magnitude of **OA** and **OB** are equal the components of **OA** and **AB** along the wall are equal and in the same direction, while those perpendicular to the wall are equal and opposite. Thus, the change in momentum is only due to the change in direction of the perpendicular components.



Hence, $\Delta\mathbf{P} = OA\sin 60° - (-OB\sin 60°)$

$= mv\sin 60° + mv\sin 60°$

$= 2mv\sin 60° = 2 \times 3 \times 100 \times \frac{\sqrt{3}}{2}$

$= 300\sqrt{3}$ kg-m/s

The force exerted on the wall

$F = \frac{\Delta\mathbf{P}}{\Delta t} = \frac{300\sqrt{3}}{0.2} = 1500\sqrt{3}$ N

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19 The force on a rocket moving with a velocity 300 m/s is 210 N. The rate of consumption of fuel of rocket is **[CBSE AIPMT 1999]**

(a) 0.7 kg/s (b) 1.4 kg/s
(c) 0.07 kg/s (d) 10.7 kg/s

Ans. *(a)*

Concept Whenever there is change in the mass w.r.t. time, apply $F = -v\frac{dm}{dt}$

Thrust force on the rocket

$$F_t = v_r\left(-\frac{dm}{dt}\right) \quad \text{(upwards)}$$

Rate of combustion of fuel

$$-\frac{dm}{dt} = \frac{F_t}{v_r}$$

Given, $F_t = 210\ \text{N}$

$v_r = 300\ \text{m/s}$

$$\therefore \quad -\frac{dm}{dt} = \frac{210}{300} = 0.7\ \text{kg/s}$$

20 A 5000 kg rocket is set for vertical firing. The exhaust speed is 800 ms^{-1}. To give an initial upward acceleration of 20 m/s^2, the amount of gas ejected per second to supply the needed thrust will be ($g = 10\ \text{ms}^{-2}$) **[CBSE AIPMT 1998]**

(a) 127.5 kg s^{-1} (b) 187.5 kg s^{-1}
(c) 185.5 kg s^{-1} (d) 137.5 kg s^{-1}

Ans. *(b)*

Thrust force on the rocket

$$F_t = v_r\left(-\frac{dm}{dt}\right) \quad \text{(upwards)}$$

Weight of the rocket

$$w = mg \quad \text{(downwards)}$$

Net force on the rocket

$$F_{net} = F_t - w$$

$$\Rightarrow \quad ma = v_r\left(\frac{-dm}{dt}\right) - mg$$

$$\Rightarrow \quad \left(\frac{-dm}{dt}\right) = \frac{m(g+a)}{v_r}$$

$\therefore$ Rate of gas ejected per second

$$= \frac{5000\,(10+20)}{800} = \frac{5000\times 30}{800}$$

$$= 187.5\ \text{kg s}^{-1}$$

21 A bullet is fired from a gun. The force on the bullet is given by

$$F = 600 - 2\times 10^5\ t$$

where, F is in newton and t in second. The force on the bullet becomes zero as soon as it leaves the barrel. What is the average impulse imparted to the bullet? **[CBSE AIPMT 1998]**

(a) 8 N-s (b) Zero
(c) 0.9 N-s (d) 1.8 N-s

Ans. *(c)*

Concept To calculate impulse first of all calculate the time during which force becomes zero.

We have given,

$$F = 600 - 2\times 10^5\ t$$

When, bullet leaves the barrel, the force on the bullet becomes zero.

$$\text{So, } 600 - 2\times 10^5\ t = 0 \Rightarrow \quad t = \frac{600}{2\times 10^5}$$

$$= 3\times 10^{-3}\text{s}$$

Then, average impulse imparted to the bullet

$$I = \int_0^t F\,dt$$

$$= \int_0^{3\times 10^{-3}} (600 - 2\times 10^5\ t)\,dt$$

$$= \left[600\,t - \frac{2\times 10^5\ t^2}{2}\right]_0^{3\times 10^{-3}}$$

$$= 600\times 3\times 10^{-3} - 10^5\times (3\times 10^{-3})^2$$

$$= 1.8 - 0.9 = 0.9\ \text{N-s}$$

Alternative

As obtained in previous method, the time taken by bullet when it leaves the barrel

$$t = 3\times 10^{-3}\text{s}$$

Let F_1 and F_2 denote the forces at the time of firing of bullets i.e. at $t = 0$ and at the time of leaving the bullet i.e. at $t = 3\times 10^{-3}$s.

$$F_1 = 600 - 2\times 10^5\times 0 = 600\ \text{N}$$

$$F_2 = 600 - 2\times 10^5\times 3\times 10^{-3} = 0$$

Mean value of force

$$F = \frac{1}{2}(F_1 + F_2) = \frac{600+0}{2} = 300\ \text{N}$$

Thus, impulse $= F\times t$

$$= 300\times 3\times 10^{-3} = 0.9\ \text{N - s}$$

22 A 10 N force is applied on a body produces an acceleration of 1 m/s^2. The mass of the body is **[CBSE AIPMT 1996]**

(a) 5 kg (b) 10 kg
(c) 15 kg (d) 20 kg

Ans. *(b)*

According to second law of motion, magnitude of force can be calculated by multiplying mass of the body and the acceleration produced in it.

or force $F = ma$

Here, $F = 10\ \text{N}$

$$a = 1\ \text{m/s}^2 \Rightarrow \therefore\ m = \frac{F}{a} = \frac{10}{1} = 10\ \text{kg}$$

23 A ball of mass 150 g moving with an acceleration 20 m/s^2 is hit by a force, which acts on it for 0.1 s. The impulsive force is **[CBSE AIPMT 1996]**

(a) 0.5 N-s (b) 0.1 N-s
(c) 0.3 N-s (d) 1.2 N-s

Ans. *(c)*

Impulse of a force, which is the product of average force during impact and the time for, which the impact lasts is measured by the total change in linear momentum produced during the impact.

Impulse $I = F_{av}\times t = \mathbf{p}_2 - \mathbf{p}_1$

Here, Mass $= 150\ \text{g} = \frac{150}{1000}\ \text{kg}$

$$\therefore \quad F = \frac{150}{1000}\times 20 = 3\ \text{N}$$

$$\therefore \quad I = F\cdot\Delta t = 3\times 0.1 = 0.3\ \text{N-s}$$

24 If the force on a rocket moving with a velocity of 300 m/s is 345 N, then the rate of combustion of the fuel is **[CBSE AIPMT 1995]**

(a) 0.55 kg/s (b) 0.75 kg/s
(c) 1.15 kg/s (d) 2.25 kg/s

Ans. *(c)*

Thrust on the rocket is the force with which the rocket moves upwards. Thrust on rocket at time t is given by $F = -u\frac{dm}{dt}$

The negative sign indicates that thrust on the rocket is in a direction opposite to the direction of escaping gases.

Here, velocity of the rocket $u = 300$ m/s and force $F = 345\ \text{N}$

$\therefore$ Rate of combustion of fuel

$$-\left(\frac{dm}{dt}\right) = \frac{F}{u} = \frac{345}{300} = 1.15\ \text{kg/s}$$

25 A satellite in a force free space sweeps stationary interplanetary dust at a rate. $\left(\frac{dM}{dt}\right) = \alpha v$. The acceleration of satellite is **[CBSE AIPMT 1994]**

(a) $-\frac{2\alpha v^2}{M}$ (b) $-\frac{\alpha v^2}{M}$ (c) $-\frac{\alpha v^2}{2M}$ (d) $-\alpha v^2$

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Ans. *(b)*

Thrust on the satellite is the force with which the satellite moves upwards in space. It is given by

$$F = -u\frac{dm}{dt}$$

Here, initial velocity

$u = v$, rate of change of mass

$$\frac{dm}{dt} = \alpha v$$

As we know that,

$$F = -v\frac{dm}{dt} = -v(\alpha v) = -\alpha v^2$$

$$\text{Acceleration} = \frac{F}{M} = -\frac{\alpha v^2}{M}$$

26 Physical independence of force is a consequence of **[CBSE AIPMT 1991]**

(a) third law of motion
(b) second law of motion
(c) first law of motion
(d) All of these

Ans. *(c)*

According to Newton's first law of motion, a body continues to be in a state of rest or of uniform motion, unless it is acted upon by an external force to change the state. Hence, Newton's first law of motion is related to physical independence of force.

27 A particle of mass m is moving with a uniform velocity v_1. It is given an impulse such that its velocity becomes v_2. The impulse is equal to **[CBSE AIPMT 1990]**

(a) $m[|v_2| - |v_1|]$ (b) $\frac{1}{2}m(v_2^2 - v_1^2)$
(c) $m(v_1 + v_2)$ (d) $m(v_2 - v_1)$

Ans. *(d)*

Concept Impulse of a force can be calculated as the product of large force applied to the small time to which force act.

i.e. $F = \frac{dp}{dt}$

$\Rightarrow$ $F \cdot dt = dp$

$\Rightarrow$ impulse $= p_2 = p_1$

Impulse of a force, which is the product of average force during impact and the time for which the impact lasts, is measured by the total change in linear momentum produced during the impact.

Here, $\mathbf{p}_1 = m\mathbf{v}_1$, $\mathbf{p}_2 = m\mathbf{v}_2$

Impulse, $I = m\mathbf{v}_2 - m\mathbf{v}_1 = m(\mathbf{v}_2 - \mathbf{v}_1)$

28 A 600 kg rocket is set for a vertical firing. If the exhaust speed is 1000 ms^{-1}, the mass of the gas ejected per second to supply the thrust needed to overcome the weight of rocket is **[CBSE AIPMT 1990]**

(a) 117.6 kg s^{-1} (b) 58.6 kg s^{-1}
(c) 6 kg s^{-1} (d) 76.4 kg s^{-1}

Ans. *(c)*

Thrust on the rocket is the force with which the rocket moves upwards.

Thrust on the rocket at time t is given by

$$F = -u\frac{dm}{dt}$$

where, u is relative velocity of exhaust gases with respect to the rocket. $\frac{dm}{dt}$ is rate of combustion of fuel at that instant.

$$\therefore \quad F = -u\frac{dm}{dt} = mg \Rightarrow -\frac{dm}{dt} = \frac{mg}{u}$$

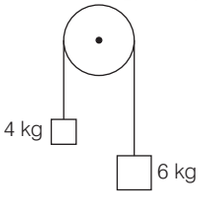
Here, $m = 600$ kg, $u = 1000$ ms^{-1}

$$\therefore \quad -\frac{dm}{dt} = \frac{600 \times 10}{1000} = 6 \text{ kg s}^{-1}$$

TOPIC 2

Equilibrium of a Particle and Common Forces in Mechanics

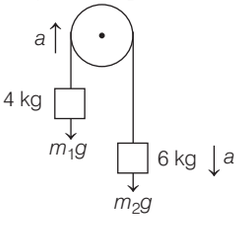
29 Two bodies of mass 4 kg and 6 kg are tied to the ends of a massless string. The string passes over a pulley which is frictionless (see figure). The acceleration of the system in terms of acceleration due to gravity g is **[NEET (Sep.) 2020]**



(a) $g/2$ (b) $g/5$ (c) $g/10$ (d) g

Ans. *(b)*

Given, $m_1 = 4$ kg, $m_2 = 6$ kg and $a = ?$



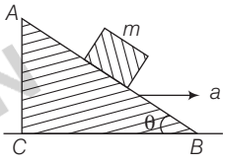
From the above free body diagram, the relation for acceleration of the given system can be given as

$$a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) \cdot g$$

$$= \left(\frac{6-4}{4+6}\right) \times g = \frac{g}{5}$$

Hence, correct option is (b).

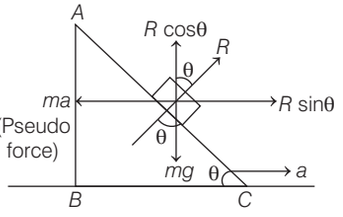
30 A block of mass m is placed on a smooth inclined wedge ABC of inclination θ as shown in the figure. The wedge is given an acceleration a towards the right. The relation between a and θ for the block to remain stationary on the wedge is **[NEET 2018]**



(a) $a = g\cos\theta$ (b) $a = \frac{g}{\sin\theta}$
(c) $a = \frac{g}{\text{cosec}\,\theta}$ (d) $a = g\tan\theta$

Ans. *(d)*

According to the question, the FBD of the given condition will be



Since, the wedge is accelerating towards right with a, thus a pseudo force acts in the left direction in order to keep the block stationary. As, the system is in equilibrium.

$\therefore$ $\Sigma F_x = 0$

or $\Sigma F_y = 0$

$\Rightarrow$ $R\sin\theta = ma$

or $mg\sin\theta = ma$ ...(i)

Similarly, $R\cos\theta = mg$

or $mg\cos\theta = mg$ ...(ii)

Dividing Eq. (i) by Eq (ii), we get

$$\frac{mg\sin\theta}{mg\cos\theta} = \frac{ma}{mg}$$

$\Rightarrow$ $\tan\theta = \frac{a}{g}$

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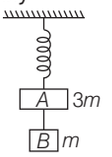
or $a = g\tan\theta$

$\therefore$ The relation between a and g for the block to remain stationary on the wedge is $a = g\tan\theta$.

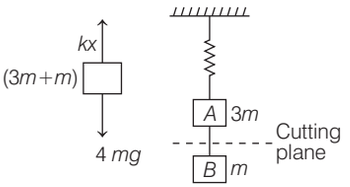
31 Two blocks A and B of masses $3m$ and m respectively are connected by a massless and inextensible string. The whole system is suspended by a massless spring as shown in figure. The magnitudes of acceleration of A and B immediately after the string is cut, are respectively **[NEET 2017]**



(a) $g, \frac{g}{3}$ (b) $\frac{g}{3}, g$ (c) g, g (d) $\frac{g}{3}, \frac{g}{3}$

Ans. ***(b)***

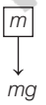
Initially system, is in equilibrium with a total weight of $4mg$ over spring.



$\therefore \quad kx = 4mg$

When string is cut at the location as shown above.

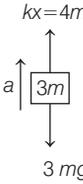
Free body diagram for m is



So, force on mass $m = mg$

$\therefore$ Acceleration of mass, $m = g$

For mass $3m$; free body diagram is



If a = acceleration of block of mass $3m$, then

$$F_{net} = 4mg - 3mg$$

$$\Rightarrow \quad 3m \cdot a_A = mg \text{ or } a_A = \frac{g}{3}$$

So, accelerations for blocks A and B are

$$a_A = \frac{g}{3} \text{ and } a_B = g$$

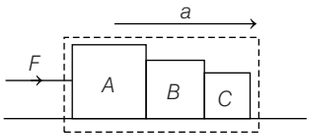
32 Three blocks A, B and C of masses 4 kg, 2 kg and 1 kg respectively, are in contact on a frictionless surface, as shown. If a force of 14 N is applied on the 4 kg block, then the contact force between A and B is **[CBSE AIPMT 2015]**

(a) 2 N (b) 6 N (c) 8 N (d) 18 N

Ans. ***(b)***

Given, $m_A = 4\,\text{kg}$

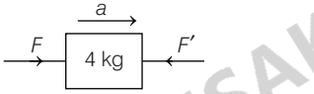
$$m_B = 2\,\text{kg} \Rightarrow m_C = 1\,\text{kg}$$



So, total mass $(M) = 4 + 2 + 1 = 7\,\text{kg}$

Now, $F = Ma \Rightarrow 14 = 7a \Rightarrow a = 2\,\text{m/s}^2$

FBD of block A,



$$F - F' = 4a$$

$$\Rightarrow \quad F' = 14 - 4\times 2 \Rightarrow F' = 6\,\text{N}$$

33 A person of mass 60 kg is inside a lift of mass 940 kg and presses the button on control panel. The lift starts moving upwards with an acceleration 1.0 m/s^2. If $g = 10\,\text{m/s}^2$, the tension in the supporting cable is **[CBSE AIPMT 2011]**

(a) 9680 N (b) 11000 N
(c) 1200 N (d) 8600 N

Ans. ***(b)***

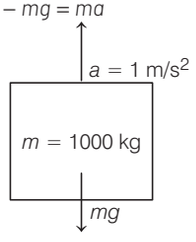
Total mass (m)

= Mass of lift + Mass of person

$= 940 + 60 = 1000$ kg

So, from the free body diagram

$$T - mg = ma$$



Hence, $T - 1000\times 10 = 1000\times 1$

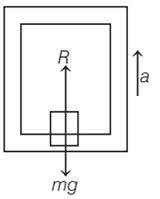
$$T = 11000\,\text{N}$$

34 The mass of a lift is 2000 kg. When the tension in the supporting cable is 28000 N, then its acceleration is **[CBSE AIPMT 2009]**

(a) 30 ms^{-2} downwards
(b) 4 ms^{-2} upwards
(c) 4 ms^{-2} downwards
(d) 14 ms^{-2} upwards

Ans. ***(b)***

Here, lift is accelerating upward at the rate of a.



Hence, equation of motion is written as

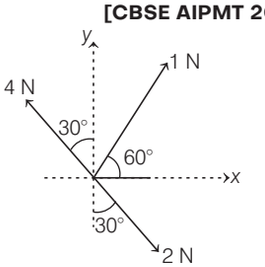
$$R - mg = ma$$

$$28000 - 20000 = 2000a$$

$$[\because g = 10\,\text{ms}^{-2}]$$

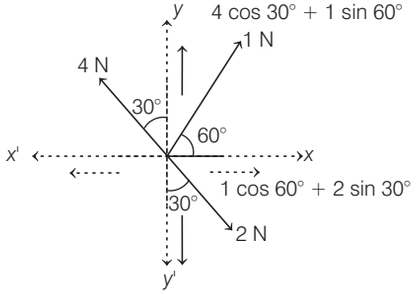
$$\Rightarrow \quad a = \frac{8000}{2000} = 4\,\text{ms}^{-2} \text{ upwards}$$

35 Three forces acting on a body are shown in the figure. To have the resultant force only along the y-direction, the magnitude of the minimum additional force needed is **[CBSE AIPMT 2008]**



(a) 0.5 N (b) 1.5 N (c) $\frac{\sqrt{3}}{4}$ N (d) $\sqrt{3}$ N

Ans. ***(a)***



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Breaking all the forces in x-y axis.

otal force along $(+x)$ axis

$= (1\cos 60° + 2\sin 30°)$

along $(-x)$ axis $= (4\sin 30°)$ along $(+y)$ axis $= (4\cos 30° + 1\sin 60°)$ along $(-y)$ axis $= (2\cos 30°)$

$\Rightarrow$ Net force along x-axis

$= -(1\cos 60° + 2\sin 30°) + 4\sin 30°$

$\Rightarrow \quad -\left(\frac{1}{2} + 2\times\frac{1}{2}\right) + 4\times\frac{1}{2}$

$\Rightarrow \quad \frac{-3}{2} + 2 = +\frac{1}{2}$

Net force along y-axis

$= 4\cos 30° + 1\sin 60° - 2\cos 30°$

$\Rightarrow \quad 4\times\frac{\sqrt{3}}{2} + \frac{\sqrt{3}}{2} - 2\times\frac{\sqrt{3}}{2} = \frac{5\sqrt{3}}{2} - \frac{2\sqrt{3}}{2}$

$= \frac{3\sqrt{3}}{2}$

To have, resultant only in y-axis we must have $\frac{1}{2}$ N force towards $+x$-axis, so that it can compensate the net force of $-x$ axis.

36 A monkey of mass 20 kg is holding a vertical rope. The rope will not break, when a mass of 25 kg is suspended from it but will break, if the mass exceeds 25 kg. What is the maximum acceleration with which the monkey can climb up along the rope? (Take $g = 10\ m/s^2$)

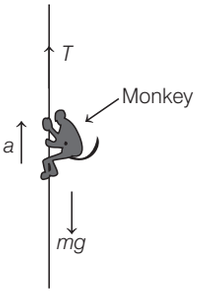
[CBSE AIPMT 2003]

(a) 25 m/s^2 (b) 2.5 m/s^2
(c) 5 m/s^2 (d) 10 m/s^2

Ans. *(b)*

Maximum bearable tension in the rope

$T = 25\times 10 = 250$ N



From the figure,

$T - mg = ma$ or acceleration $a = \frac{T - mg}{m}$

Given, mass $m = 20$ kg,

$g = 10\ m/s^2$,

Taking, $T = 250$ N

Hence, $a = \frac{250 - 20\times 10}{20} = \frac{50}{20}$

$= 2.5\ m/s^2$

37 A man weighs 80 kg. He stands on a weighing scale in a lift which is moving upwards with a uniform acceleration of 5 m/s^2. What would be the reading on the scale? (Take $g = 10\ m/s^2$)

[CBSE AIPMT 2003]

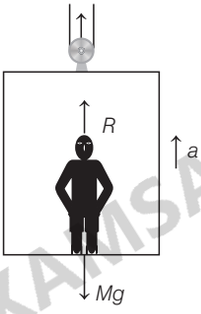
(a) 800 N (b) 1200 N
(c) Zero (d) 400 N

Ans. *(b)*

Mass of man $M = 80$ kg

Acceleration of lift, $a = 5\ m/s^2$

When, lift is moving upwards, the reading of weighing scale will be equal to R.



The equation of motion gives

$R - Mg = Ma$ or

$R = Mg + Ma = M(g + a)$

$\therefore \quad R = 80\,(10 + 5) = 80\times 15 = 1200$ N

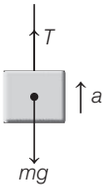
38 A lift of mass 1000 kg is moving upwards with an acceleration of 1 m/s^2. The tension developed in the string, which is connected to lift is ($g = 9.8\ m/s^2$)

[CBSE AIPMT 2002]

(a) 9800 N (b) 10800 N
(c) 11000 N (d) 10000 N

Ans. *(b)*

When, lift move upwards with same acceleration, then according to free body diagram of the left



$T - mg = ma$

or $T = m(g + a)$

Given,

$m = 1000$ kg, $a = 1\ m/s^2$,

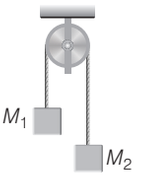
$g = 9.8\ m/s^2$

Thus, $T = 1000\,(9.8 + 1) = 1000\times 10.8$

$= 10800$ N

39 Two masses $M_1 = 5$ kg, $M_2 = 10$ kg are connected at the ends of an inextensible string passing over a frictionless pulley as shown. When masses are released, then acceleration of masses will be

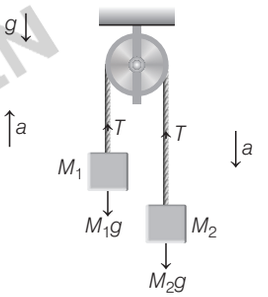
[CBSE AIPMT 2000]



(a) g (b) $\frac{g}{2}$ (c) $\frac{g}{3}$ (d) $\frac{g}{4}$

Ans. *(c)*

Concept In the case of masses hanging from a pulley by a string, the tension in whole string is same, say equal to T.



As $M_2 > M_1$, so mass M_2 moves down and mass M_1 moves up with the same acceleration a (say). The arrangement of the motion is represented in the figure.

According to free body diagram of mass M_2, is

$$M_2 g - T = M_2 a \qquad ...(i)$$

According to free body diagram of mass M_1, is

$$T - M_1 g = M_1 a \qquad ...(ii)$$

Adding Eqs. (i) and (ii), we get

$(M_2 g - T) + (T - M_1 g) = (M_1 + M_2)a$

$(M_2 - M_1)g = (M_1 + M_2)a$

$\Rightarrow \quad a = \left(\frac{M_2 - M_1}{M_1 + M_2}\right)g$

Given, $M_1 = 5$ kg, $M_2 = 10$ kg

Hence, $a = \left(\frac{10 - 5}{5 + 10}\right)g = \frac{5}{15}g = \frac{g}{3}\ m/s^2$

Alternative

Acceleration,

$a = \frac{(F_{net})\text{system}}{\text{Net mass}} = \frac{(10 - 5)\times g}{5 + 10} = \frac{g}{3}\ m/s^2$

In a mass-pulley system, the tension in the string is always towards the pulley.

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40 A mass of 1 kg is suspended by a thread. It is

1. lifted up with an acceleration 4.9 m/s^2,

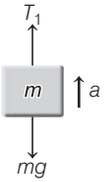
2. lowered with an acceleration 4.9 m/s^2.

The ratio of the tensions is **[CBSE AIPMT 1998]**

(a) 3 : 1 (b) 1 : 3 (c) 1 : 2 (d) 2 : 1

Ans. *(a)*

(i) When, mass is lifted upwards with an acceleration a, then according to free body diagram



$$T_1 - mg = ma \Rightarrow T_1 = mg + ma$$

$$T_1 = m(g + a)$$

Substituting the values, we obtain

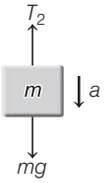
$$\therefore \quad T_1 = (1)(9.8 + 4.9) = 14.7 \text{ N}$$

(ii) When, mass is lowered downwards with an acceleration a, then

$$mg - T_2 = ma$$

$$\Rightarrow T_2 = mg - ma = m(g - a)$$

Substituting the values, we have



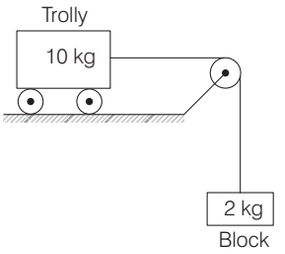
$$T_2 = (1)(9.8 - 4.9) = 4.9 \text{ N}$$

Then, ratio of tensions

$$\frac{T_1}{T_2} = \frac{14.7}{4.9} = \frac{3}{1} \Rightarrow T_1 : T_2 = 3 : 1$$

TOPIC 3
Friction

41 Calculate the acceleration of the block and trolly system shown in the figure. The coefficient of kinetic friction between the trolly and the surface is 0.05. ($g = 10$ m/s^2, mass of the string is negligible and no other friction exists). **[NEET (Oct.) 2020]**

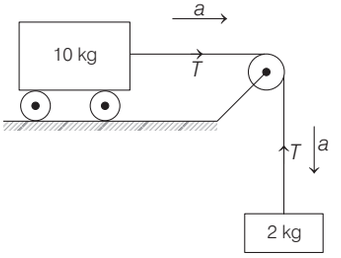


(a) 1.25 m/s^2 (b) 1.50 m/s^2

(c) 1.66 m/s^2 (d) 1.00 m/s^2

Ans. *(a)*

The given situation is shown in the following diagram.



If 'a' be the acceleration of the system then, equation of motion of 10 kg trolly,

$$T - \mu R = 10a$$

$$\Rightarrow \quad T - 0.05 \times 10g = 10a \quad [\because \mu = 0.05,\ R = 10g]$$

$$\Rightarrow \quad T - 0.05 \times 10 \times 10 = 10a$$

$$\Rightarrow \quad T - 5 = 10a \quad \ldots (i)$$

Equation of motion of 2kg block,

$$2g - T = 2a$$

$$2 \times 10 - T = 2a$$

$$20 - T = 2a \quad \ldots (ii)$$

Adding Eqs. (i) and (ii), we have

$$20 - 5 = 12a$$

$$\Rightarrow \quad 15 = 12a$$

$$\Rightarrow \quad a = \frac{15}{12} = \frac{5}{4} = 1.25 \text{ ms}^{-2}$$

42 Two particles A and B are moving in uniform circular motion in concentric circles of radii r_A and r_B with speed v_A and v_B respectively. Their time period of rotation is the same. The ratio of angular speed of A to that of B will be **[NEET (National) 2019]**

(a) $v_A : v_B$ (b) $r_B : r_A$ (c) 1 : 1 (d) $r_A : r_B$

Ans. *(c)*

The angular speed of a particle in a uniform circular motion is given by

$$\omega = \frac{\text{angle of circle}}{\text{Time}}$$

$\omega = \dfrac{2\pi}{T}$, where T is the time period of rotation

For particle A, $\omega_A = \dfrac{2\pi}{T_A}$

For particle B, $\omega_B = \dfrac{2\pi}{T_B}$

$$\therefore \frac{\omega_A}{\omega_B} = \frac{2\pi}{T_A} \times \frac{T_B}{2\pi} = \frac{T_B}{T_A}$$

$$= \frac{1}{1} \text{ or } 1 : 1 \quad [\because T_A = T_B \text{ (given)}]$$

43 A body of mass m is kept on a rough horizontal surface (coefficient of friction = μ). Horizontal force is applied on the body, but it does not move. The resultant of normal reaction and the frictional force acting on the object is given F, where F is **[NEET (Odisha) 2019]**

(a) $|F| = mg + \mu\, mg$

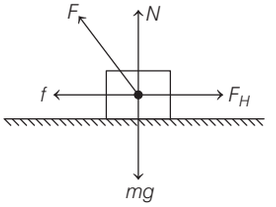
(b) $|F| = \mu mg$

(c) $|F| \le mg\sqrt{1 + \mu^2}$

(d) $|F| = mg$

Ans. *(c)*

The situation can be drawn as



The frictional force, $f = \mu N = \mu\, mg \quad [\because N = mg]$

From Free body diagram (*FBD*), the resultant force is

$$|\mathbf{F}| = \sqrt{N^2 + f^2}$$

$$= \sqrt{(mg)^2 + (\mu mg)^2}$$

$$= mg\sqrt{1 + \mu^2}$$

This is the minimum force required to move the object. But as the body is not moving

$$\therefore \quad |\mathbf{F}| \le mg\sqrt{1 - \mu^2}$$

44 Which one of the following statements is incorrect? **[NEET 2018]**

(a) Frictional force opposes the relative motion

(b) Limiting value of static friction is directly proportional to normal reaction

(c) Rolling friction is smaller than sliding friction

(d) Coefficient of sliding friction has dimensions of length

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Ans. *(d)*

The opposing force that comes into play when one body is actually sliding over the surface of the other body is called sliding friction.

The coefficient of sliding is given as

$$\mu_S = \frac{N}{F_{\text{sliding}}}$$

where, N is the normal reaction and F_{sliding} is the sliding force.

As, the dimensions of N and F_{sliding} are same. Thus, μ_S is a dimensionless quantity.

Hence, statement(d) is incorrect.

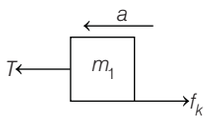
45 A block A of mass m_1 rests on a horizontal table. A light string connected to it passes over a frictionless pulley at the edge of table and from its other end another block B of mass m_2 is suspended. The coefficient of kinetic friction between the block and the table is μ_k. When the block A is sliding on the table, the tension in the string is **[CBSE AIPMT 2015]**

(a) $\frac{(m_2 + \mu_k m_1)g}{(m_1 + m_2)}$ (b) $\frac{(m_2 - \mu_k m_1)g}{(m_1 + m_2)}$

(c) $\frac{m_1 m_2 (1+\mu_k) g}{(m_1 + m_2)}$ (d) $\frac{m_1 m_2 (1-\mu_k) g}{(m_1 + m_2)}$

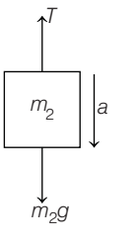
Ans. *(c)*

FBD of block A,



$$T - m_1 a = f_k \quad \ldots(i)$$

FBD of block B,



$$m_2 g - T = m_2 a \quad \ldots(ii)$$

Adding Eqs. (i) and (ii), we get

$$m_2 g - m_1 a = m_2 a + f_k$$

$$\Rightarrow \quad m_2 g - m_1 a = m_2 a + \mu_k m_1 g$$

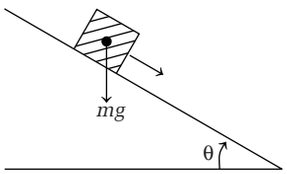
$$\Rightarrow \quad a = \frac{(m_2 - \mu_k m_1)g}{m_1 + m_2}$$

From Eq. (ii), $T = m_2 (g - a)$

$$= m_2 \left[1 - \frac{(m_2 - \mu_k m_1)}{m_1 + m_2}\right] g$$

$$T = \frac{m_1 m_2 (1 + \mu_k)}{m_1 + m_2} g$$

46 A plank with a box on it at one end is gradually raised about the other end. As the angle of inclination with the horizontal reaches 30°, the box starts to slip and slides 4.0 m down the plank in 4.0 s. The coefficients of static and kinetic friction between the box and the plank will be, respectively **[CBSE AIPMT 2015]**

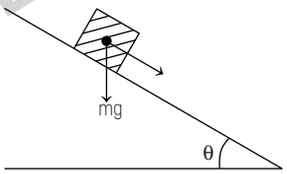


(a) 0.6 and 0.6 (b) 0.6 and 0.5

(c) 0.5 and 0.6 (d) 0.4 and 0.3

Ans. *(b)*

Given a plank with a box on its one end is gradually raised about the end having angle of inclination is 30°, the box starts to slip and slides down 4 m the plank in 4 s as shown in figure.



The coefficient of static friction,

$$\mu_s = \tan 30° = \frac{1}{\sqrt{3}} = 0.6$$

So, distance covered by a plank,

$$s = ut + \frac{1}{2} a t^2$$

Here, $u = 0$ and $a = g(\sin\theta - \mu \cos\theta)$

$$\therefore \quad 4 = \frac{1}{2} g (\sin 30° - \mu_k \cos 30°) (4)^2$$

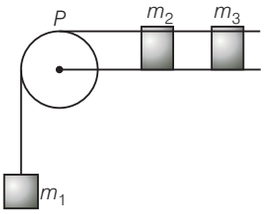
$$\Rightarrow \quad 0.5 = 10 \times \frac{1}{2} - \mu_K \times 10 \times \frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad 5\sqrt{3}\,\mu_K = 4.5$$

$$\Rightarrow \quad \mu_K = 0.51$$

Thus, coefficient of kinetic friction between the box and the plank is 0.51.

47 A system consists of three masses m_1, m_2 and m_3 connected by a string passing over a pulley P. The mass m_1 hangs freely and m_2 and m_3 are on a rough horizontal table (the coefficient of friction $= \mu$). The pulley is frictionless and of negligible mass. The downward acceleration of mass m_1 is (Assume, $m_1 = m_2 = m_3 = m$) **[CBSE AIPMT 2014]**

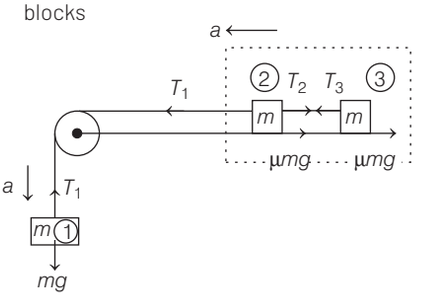


(a) $\frac{g(1-g\mu)}{9}$ (b) $\frac{2g\mu}{3}$

(c) $\frac{g(1-2\mu)}{3}$ (d) $\frac{g(1-2\mu)}{2}$

Ans. *(c)*

First of all consider the forces on the blocks



For the Ist block, $[\because m_1 = m_2 = m_3]$

$$mg - T_1 = m \times a \quad \ldots(i)$$

Let us consider 2nd and 3rd block as a system.

So, $T_1 - 2\mu mg = 2m \times a \quad \ldots(ii)$

Solving Eqs. (i) and (ii),

$$\Rightarrow \quad mg - T_1 = m \times a$$

$$\Rightarrow \quad T_1 - 2\mu mg = 2m \times a$$

Addiing Eqs. (i) and (ii)

$$mg(1 - 2\mu) = 3m \times a \;\Rightarrow\; a = \frac{g}{3}(1 - 2\mu)$$

48 Three blocks with masses $m, 2m$ and $3m$ are connected by strings, as shown in the figure. After an upward force F is applied on block m, the masses move upward at constant speed v. What is the net

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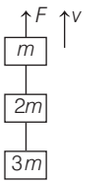
force on the block of mass $2m$? (g is the acceleration due to gravity). **[NEET 2013]**



(a) Zero (b) $2\ mg$
(c) $3\ mg$ (d) $6\ mg$

Ans. ***(a)***

Since, all the blocks are moving with constant velocity and we know that, if velocity is constant, acceleration of the body becomes zero. Hence, the net force on all the blocks will be zero.

49 The upper half of an inclined plane of inclination θ is perfectly smooth while lower half is rough. A block starting from rest at the top of the plane will again come to rest at the bottom, if the coefficient of friction between the block and lower half of the plane is given by **[NEET 2013]**

(a) $\mu = \frac{1}{\tan\theta}$

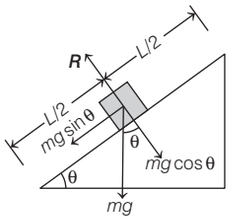
(b) $\mu = \frac{2}{\tan\theta}$

(c) $\mu = 2\tan\theta$

(d) $\mu = \tan\theta$

Ans. ***(c)***

Concept Net work done by the block in going from top to bottom of the inclined plane, must be equal to the work done by frictional force.



The block may be stationary, when

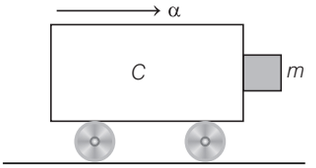
$$mg\sin\theta\cdot L = \mu\, mg\cos\theta\frac{L}{2}$$

or $$\mu = \frac{mg\sin\theta\cdot L}{mg\cos\theta\cdot\frac{L}{2}}$$

$$= 2\frac{\sin\theta}{\cos\theta} = 2\tan\theta$$

$$\mu = 2\tan\theta$$

50 A block of mass m is in contact with the cart C as shown in the figure.



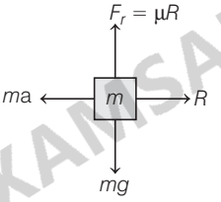
The coefficient of static friction between the block and the cart is μ. The acceleration α of the cart that will prevent the block from falling satisfies **[CBSE AIPMT 2010]**

(a) $\alpha > \frac{mg}{\mu}$ (b) $\alpha > \frac{g}{\mu m}$

(c) $\alpha \geq \frac{g}{\mu}$ (d) $\alpha < \frac{g}{\mu}$

Ans. ***(c)***

When, a cart moves with some acceleration towards right, then a pseudo force ($m\alpha$) acts on block towards left. This force ($m\alpha$) is action force by a block on cart



Now, block will remain static w.r.t. cart, if frictional force $\mu R \geq mg$

$\Rightarrow$ $\mu\, m\alpha \geq mg$ [as $R = m\alpha$]

$\Rightarrow$ $\alpha \geq \frac{g}{\mu}$

51 A block B is pushed momentarily along a horizontal surface with an initial velocity v. If μ is the coefficient of sliding friction between B and the surface, block B will come to rest after a time **[CBSE AIPMT 2007]**

(a) $\frac{v}{g\mu}$ (b) $\frac{g\mu}{v}$ (c) $\frac{g}{v}$ (d) $\frac{v}{g}$

Ans. ***(a)***

Block B will come to rest, if force applied to it will vanish due to frictional force acting between block B and surface, i.e.

frictional force = force applied

i.e. $\mu mg = ma$

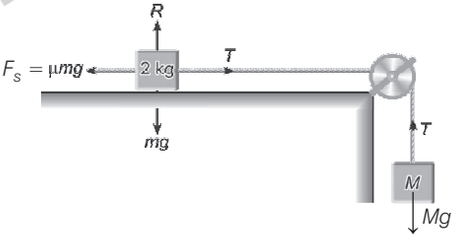
or $\mu mg = m\left(\frac{v}{t}\right)$ or $t = \frac{v}{\mu g}$

52 The coefficient of static friction, μ_s, between block A of mass 2 kg and the table as shown in the figure, is 0.2. What would be the maximum mass value of block B, so that the two blocks do not move ? The string and the pulley are assumed to be smooth and massless ($g = 10\ m/s^2$) **[CBSE AIPMT 2004]**

(a) 2.0 kg (b) 4.0 kg
(c) 0.2 kg (d) 0.4 kg

Ans. ***(d)***

Let the mass of the block B be M.



In equilibrium,

$T - Mg = 0 \Rightarrow T = Mg$ ...(i)

If blocks do not move, then

$T = f_s$

where, f_s = frictional force

$= \mu_s R = \mu_s\, mg$

$\therefore$ $T = \mu_s\, mg$ ...(ii)

Thus, from Eqs. (i) and (ii), we have

$Mg = \mu_s\, mg$ or $M = \mu_s\, m$

Given, $\mu_s = 0.2$, $m = 2$ kg

$\therefore$ $M = 0.2 \times 2 = 0.4$ kg

53 A block of mass 10 kg is placed on a rough horizontal surface having coefficient of friction $\mu = 0.5$. If a horizontal force of 100 N is applied on it, then the acceleration of the block will be ($\text{Take} g = 10\ m/s^2$) **[CBSE AIPMT 2002]**

(a) $15\ m/s^2$ (b) $10\ m/s^2$
(c) $5\ m/s^2$ (d) $0.5\ m/s^2$

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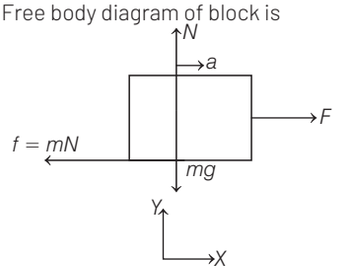
Ans. *(c)*

Free body diagram of block is



From Newton's second law along X-axis

$$\Sigma F_x = ma$$

i.e. $F - f = ma$

or $F - \mu mg = ma$

or $a = \dfrac{F - \mu mg}{m}$

Given, $F = 100\ \text{N}, \mu = 0.5, m = 10\ \text{kg}$,

$g = 10\ \text{m/s}^2$

Substituting, the values in the above relation for acceleration of block,

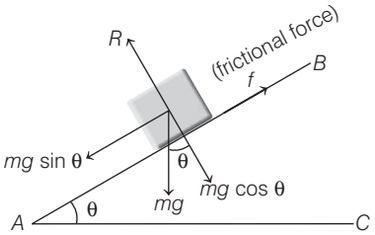
$$a = \frac{(100) - (0.5)(10)(10)}{(10)} = 5\ \text{m/s}^2$$

54 A block has been placed on an inclined plane with the slope angle θ, block slides down the plane at constant speed. The coefficient of kinetic friction is equal to **[CBSE AIPMT 1993]**

(a) $\sin\theta$ (b) $\cos\theta$
(c) g (d) $\tan\theta$

Ans. *(d)*

Angle of repose or angle of sliding is defined as the minimum angle of inclination of a plane with the horizontal, such that a body placed on the plane just begins to slide down.



AB is an inclined plane such that a body placed on it just begins to slide down

$\angle BAC = \theta$ = angle of repose

In equilibrium,

$$f = mg\sin\theta$$

and $R = mg\cos\theta$

$$\therefore \quad \frac{f}{R} = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta$$

i.e. $\mu = \tan\theta$

NOTE

Coefficient of kinetic friction between any two surfaces in contact is equal to the tangent of the angle of inclination between them.

55 Consider, a car moving along a straight horizontal road with a speed of 72 km/h. If the coefficient of static friction between the tyres and the road is 0.5, the shortest distance in which the car can be stopped is (Take $g = 10\ \text{m/s}^2$) **[CBSE AIPMT 1992]**

(a) 30 m (b) 40 m (c) 72 m (d) 20 m

Ans. *(b)*

When, static friction is present, then acceleration of body is given by $a = -\mu g$

Here, initial velocity

$$u = 72\ \text{km h}^{-1} = 72 \times \frac{5}{18} = 20\ \text{m/s}$$

Final velocity $v = 0$

$$\therefore \quad a = -\mu g = -0.5 \times 10 = -5\ \text{m/s}^2$$

Now, from third equation of motion,

i.e. $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a} = \frac{0 - (20)^2}{2 \times (-5)} = 40\ \text{m}$$

56 A heavy uniform chain lies on horizontal table top. If the coefficient of friction between the chain and the table surface is 0.25, then the maximum friction of the length of the chain that can hang over one edge of the table is **[CBSE AIPMT 1991]**

(a) 20% (b) 25% (c) 35% (d) 15%

Ans. *(a)*

The force of friction should balance the weight of chain hanging. If M is the mass of whole chain of length L and x is the length of chain hanging to balance, then

$$\mu \frac{M}{L}(L - x)\, g = \frac{M}{L} xg$$

or $\mu (L - x) = x$

or $x = \dfrac{\mu L}{\mu + 1} = \dfrac{0.25\, L}{1.25}$ (As, $\mu = 0.25$)

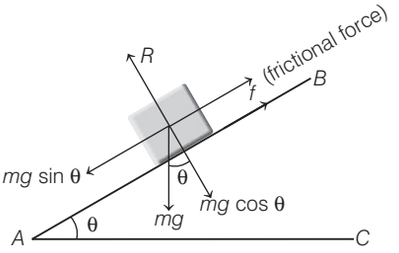
$$\therefore \quad x = \frac{L}{5} \text{ or } \frac{x}{L} = \frac{1}{5} = \frac{1}{5} \times 100 = 20\%$$

57 Starting from rest, a body slides down a 45° inclined plane in twice the time it takes to slide down the same distance in the absence of friction. The coefficient of friction between the body and the inclined plane is **[CBSE AIPMT 1988]**

(a) 0.80 (b) 0.75
(c) 0.25 (d) 0.33

Ans. *(b)*

When, a plane is inclined to the horizontal at an angle θ, which is greater than the angle of repose, the body placed on the inclined plane slides down with an acceleration a.



As, it is clear from figure

$$R = mg\cos\theta \qquad \ldots(i)$$

Net force on the body down the inclined plane which means it is sliding downwards

$$F = mg\sin\theta - f \qquad \ldots(ii)$$

i.e. $F = ma = mg\sin\theta - \mu R \quad (f = \mu R)$

$$\therefore \quad ma = mg\sin\theta - \mu\, mg\cos\theta$$

$$= mg(\sin\theta - \mu\cos\theta)$$

Hence, $a = g(\sin\theta - \mu\cos\theta)$

$\therefore$ Time taken by body to slide down the plane

$$t_1 = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2s}{g(\sin\theta - \mu\cos\theta)}}$$

When friction is absent, then time taken to slide down the plane

$$t_2 = \sqrt{\frac{2s}{g\sin\theta}} \Rightarrow \because \ t_1 = 2t_2 \quad \text{(given)}$$

$$\therefore \quad t_1^2 = 4t_2^2$$

or $\dfrac{2s}{g(\sin\theta - \mu\cos\theta)} = \dfrac{2s \times 4}{g\sin\theta}$

or $\sin\theta = 4\sin\theta - 4\mu\cos\theta$

or $\mu = \dfrac{3}{4}\tan\theta = \dfrac{3}{4}\tan 45°$

$$\therefore \quad \mu = \frac{3}{4} = 0.75$$

TOPIC 4
Dynamics of Circular Motion

58 A block of mass 10 kg is in contact against the inner wall of a hollow cylindrical drum of radius 1 m. The coefficient of friction between the block and the inner wall of the cylinder is 0.1. The minimum angular velocity needed for the

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cylinder to keep the block stationary when the cylinder is vertical and rotating about its axis, will be ($g = 10\ m/s^2$)

[NEET (National) 2019]

(a) $\frac{10}{2\pi}$ rad/s (b) 10 rad/s

(c) 10π rad/s (d) $\sqrt{10}$ rad/s

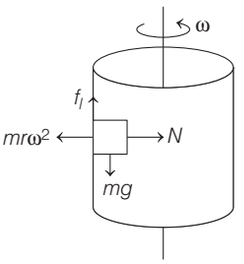
Ans. *(b)*

Given, mass of cylinder $m = 10$ kg,

radius of cylinder, $r = 1$ m

coefficient of friction, $\mu = 0.1$.

The given situation can be as shown in the figure given below.



From the above figure, it can be concluded that the block will be stationary when the limiting friction (f_l) is equal to or greater than the downward force or weight of block, i.e.

$$f_l \geq mg \quad ...(i)$$

Also, the magnitude of limiting friction between two bodies is directly proportional to the normal reaction (N) between them, i.e.

$$f_l \propto N \text{ or } f_l = \mu N \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\mu N \geq mg \text{ or } \mu(mr\omega^2) \geq mg \quad [\because N = mr\omega^2]$$

$$\Rightarrow \omega \geq \sqrt{\frac{g}{r\mu}}$$

Thus, the minimum angular velocity is

$$\omega_{min} = \sqrt{\frac{g}{r\mu}} = \sqrt{\frac{10}{1 \times 0.1}} = 10 \text{ rad/s}$$

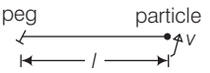
59 One end of the string of length *l* is connected to a particle of mass *m* and the other end is connected to a small peg on a smooth horizontal table. If the particle moves in circle with speed *v*, the net force on the particle (directed towards center) will be (*T* represents the tension in the string) **[NEET 2017]**

(a) T (b) $T + \frac{mv^2}{l}$

(c) $T - \frac{mv^2}{l}$ (d) Zero

Ans. *(a)*

Consider the string of length l connected to a particle as shown in the figure.



Speed of the particle is *v*. As the particle is in uniform circular motion, net force on the particle must be equal to centripetal force which is provided by the tension (T).

$\therefore$ Net force = Centripetal force

$$\Rightarrow \frac{mv^2}{l} = T$$

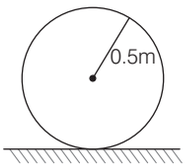
60 A uniform circular disc of radius 50 cm at rest is free to turn about an axis which is perpendicular to its plane and passes through its centre. It is subjected to a torque which produces a constant angular acceleration of 2.0 rad s^{-2}. Its net acceleration in ms^{-2} at the end of 2.0 s is *a* approximately **[NEET 2016]**

(a) 7.0 (b) 6.0

(c) 3.0 (d) 8.0

Ans. *(d)*

According to given question, a uniform circular disc of radius 50 cm at rest is free to turn about an axis having perpendicular to its plane and passes through its centre. This situation can be shown by the figure given below:



$\therefore$ Angular acceleration, $\alpha = 2$ rad s^{-2} (given)

Angular speed, $\omega = \alpha t = 4$ rad s^{-1}

$\because$ Centripetal acceleration, $a_c = \omega^2 r$

$= (4)^2 \times 0.5$

$= 16 \times 0.5$

$a_c = 8\ m/s^2$

$\because$ Linear acceleration at the end of 2*s*,

$$a_t = \alpha r = 2 \times 0.5 \Rightarrow a_t = 1\ m/s^2$$

Therefore, the net acceleration at the end of 2.0 s is given by

$$a = \sqrt{a_c^2 + a_t^2}$$

$$a = \sqrt{(8)^2 + (1)^2} = \sqrt{65} \Rightarrow a \approx 8\ m/s^2$$

61 A car is negotiating a curved road of radius *R*. The road is banked at angle θ. The coefficient of friction between the tyres of the car and the road is μ_s. The maximum safe velocity on this road is **[NEET 2016]**

(a) $\sqrt{gR\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$

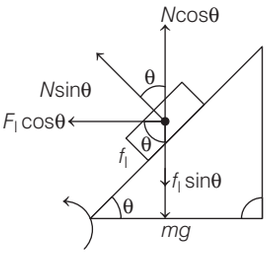
(b) $\sqrt{\frac{g}{R}\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$

(c) $\sqrt{\frac{g}{R^2}\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$

(d) $\sqrt{gR^2\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$

Ans. *(a)*

According to question, a car is negotiating a curved road of radius *R*. The road is banked at angle θ and the coefficient of friction between the tyres of car and the road is μ_s. So, this given situation can be drawn as shown in figure below.



Considering the case of vertical equilibrium

$$N\cos\theta = mg + f_l \sin\theta$$

$$\Rightarrow mg = N\cos\theta - f_l \sin\theta \quad ...(i)$$

Considering the case of horizontal equilibrium,

$$N\sin\theta + f_l \cos\theta = \frac{mv^2}{R} \quad ...(ii)$$

Divide eqs. (i) and (ii), we get

$$\frac{v^2}{Rg} = \frac{\sin\theta + \mu_s \cos\theta}{\cos\theta - \mu_s \sin\theta} \quad [f_l \propto \mu_s]$$

$$\Rightarrow v = \sqrt{Rg\left(\frac{\sin\theta + \mu_s \cos\theta}{\cos\theta - \mu_s \sin\theta}\right)}$$

$$\Rightarrow v = \sqrt{Rg\left(\frac{\tan\theta + \mu_s}{1 - \mu_s \tan\theta}\right)}$$

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62 A car of mass 1000 kg negotiates a banked curve of radius 90 m on a frictionless road. If the banking angle is 45°, the speed of the car is **[CBSE AIPMT 2012]**

(a) 20 ms^{-1}
(b) 30 ms^{-1}
(c) 5 ms^{-1}
(d) 10 ms^{-1}

Ans. *(b)*

The angle of banking

$$\tan\theta = \frac{v^2}{rg}$$

Given, $\theta = 45°$

Radius of banked curve road

$r = 90$ m and $g = 10$ m/s^2

$$\Rightarrow \quad \tan 45° = \frac{v^2}{90 \times 10}$$

$$v = \sqrt{90 \times 10 \times \tan 45°}$$

$$= \sqrt{90 \times 10 \times 1} = 30 \text{ m/s}$$

63 A gramophone record is revolving with an angular velocity ω. A coin is placed at a distance r from the centre of the record. The static coefficient of friction is μ. The coin will revolve with the record if **[CBSE AIPMT 2010]**

(a) $r = \mu g\omega^2$ (b) $r < \frac{\omega^2}{\mu g}$

(c) $r \le \frac{\mu g}{\omega^2}$ (d) $r \ge \frac{\mu g}{\omega^2}$

Ans. *(c)*

When the disc spins, the frictional force between the gramophone record and coin is μmg.

The coin will revolve with record, if

$$F_{\text{frictional}} \ge F_{\text{centripetal}}$$

i.e. $\mu mg \ge m\omega^2 r$

$$\frac{\mu g}{r} \ge \omega^2$$

64 A ball of mass 0.25 kg attached to the end of a string of length 1.96 m is moving in a horizontal circle. The string will break if the tension is more than 25 N. What is the maximum speed with which the ball can be moved ? **[CBSE AIPMT 1998]**

(a) 14 m/s (b) 3 m/s
(c) 3.92 m/s (d) 5 m/s

Ans. *(a)*

For a ball to move in horizontal circle, the ball should satisfy the condition

Tension in the string = Centripetal force

$$\Rightarrow \quad T_{\max} = \frac{Mv_{\max}^2}{R}$$

$$\Rightarrow \quad v_{\max} = \sqrt{\frac{T_{\max} \cdot R}{M}} \qquad \ldots(i)$$

Making substitution, we obtain

$$v_{\max} = \sqrt{\frac{25 \times 1.96}{0.25}} = \sqrt{196} = 14 \text{ m/s}$$

In a vertical circle, the tension at the highest point is zero and at lowest point is maximum.

65 What will be the maximum speed of a car on a road turn of radius 30 m, if the coefficient of friction between the tyres and the road is 0.4 ? (Take $g = 9.8$ m / s^2) **[CBSE AIPMT 1995]**

(a) 10.84 m/s
(b) 9.84 m/s
(c) 8.84 m/s
(d) 6.84 m/s

Ans. *(a)*

When a vehicle goes round a curved road, it requires some centripetal force. While rounding the curve, the wheels of the vehicle have a tendency to leave the curved path and regain the straight line path. Force of friction between the wheels and the road opposes this tendency of the wheels. This force (of friction) therefore, acts towards the centre of the circular track and provides the necessary centripetal force.

If v is the velocity of the vehicle while rounding the curve, the centripetal force required $= \frac{mv^2}{r}$

As, this force is provided only by the force of friction,

$$\frac{mv^2}{r} \le \mu mg \Rightarrow v^2 \le \mu rg \Rightarrow v \le \sqrt{\mu rg}$$

$$\therefore \quad v_{\max} = \sqrt{\mu rg}$$

Here, radius of curved road $r = 30$ m,

coefficient of friction $\mu = 0.4$

$$\therefore \quad v_{\max} = \sqrt{0.4 \times 30 \times 9.8}$$

$$= 10.84 \text{ m/s}$$

66 Two racing cars of masses m and $4m$ are moving in circles of radii r and $2r$ respectively. If their speeds are such that each makes a complete circle in the same time, then the ratio of the angular speeds of the first to the second car is **[CBSE AIPMT 1995]**

(a) 8 : 1 (b) 4 : 1 (c) 2 : 1 (d) 1 : 1

Ans. *(d)*

As both cars take the same time to complete the circle and as $\omega = \frac{2\pi}{t}$,

therefore ratio of angular speeds of the cars will be 1 : 1.

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05

Work, Energy and Power

TOPIC 1
Work and Energy

01 A particle is released from height S from the surface of the Earth. At a certain height its kinetic energy is three times its potential energy. The height from the surface of earth and the speed of the particle at that instant are respectively **[NEET 2021]**

(a) $\frac{S}{4}, \frac{3gS}{2}$ (b) $\frac{S}{4}, \frac{\sqrt{3gS}}{2}$

(c) $\frac{S}{2}, \frac{\sqrt{3gS}}{2}$ (d) $\frac{S}{4}, \sqrt{\frac{3gS}{2}}$

Ans. *(d)*

Let the particle at height S from the surface of the Earth is as shown.

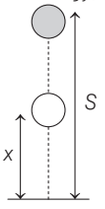
Given, at height x, kinetic energy = 3 (potential energy)

$\Rightarrow \quad KE = 3\,mgx$

At height S, total energy, TE = PE + KE

$TE = mgS + 0 = mgS$

At height x, total energy,



$TE = PE + KE$

$TE = mgx + 3mgx$

$mgS = 4mgx$

$\Rightarrow \quad x = \frac{S}{4}$ ...(i)

Now, we shall determine the speed of the particle at this height.

As, $KE = 3 \times mgx$

$KE = 3 \times mg\frac{S}{4}$ [from Eq. (i)]

$\frac{1}{2}mv^2 = \frac{3}{4}mgS$

$\Rightarrow \quad v = \sqrt{\frac{3}{2}gS}$

02 The energy required to break one bond in DNA is 10^{-20} J. This value (in eV) is nearly **[NEET (Sep.) 2020]**

(a) 0.6 (b) 0.06

(c) 0.006 (d) 6

Ans. *(b)*

Given, $E = 10^{-20}$ J

In terms of eV, we get

$$E = \frac{10^{-20}}{1.6 \times 10^{-19}}\,eV = 0.06\,eV$$

Hence, correct option is (b).

03 A force $F = 20 + 10y$ acts on a particle in y-direction, where F is in newton and y in meter. Work done by this force to move the particle from $y = 0$ to $y = 1$ m is **[NEET (National) 2019]**

(a) 5 J (b) 25 J

(c) 20 J (d) 30 J

Ans. *(b)*

Work done by a force F, which is variable in nature in moving a particle from y_1 to y_2 is given by

$$W = \int_{y_1}^{y_2} F \cdot dy \qquad \text{...(i)}$$

Here, force, $F = 20 + 10y$, $y_1 = 0$

and $y_2 = 1$ m

Substituting the given values in Eq. (i), we get

$$\Rightarrow W = \int_0^1 (20 + 10y)dy = \left[20y + \frac{10y^2}{2}\right]_0^1$$

$$= 20(1-0) + 5(1-0)^2 = 25\,J$$

$\therefore$ Work done will be 25 J.

04 A particle of mass 10 g moves along a circle of radius 6.4 cm with a constant tangential acceleration. What is the magnitude of this acceleration, if the kinetic energy of the particle becomes equal to 8×10^{-4} J by the end of the second revolution after the beginning of the motion? **[NEET 2016]**

(a) 0.15 m/s^2 (b) 0.18 m/s^2

(c) 0.2 m/s^2 (d) 0.1 m/s^2

Ans. *(d)*

Given, mass of particle $m = 0.01$ kg.

Radius of circle along which particle is moving,

$r = 6.4$ cm.

$\because$ Kinetic energy of particle,

$KE = 8 \times 10^{-4}$ J

$\Rightarrow \quad \frac{1}{2}mv^2 = 8 \times 10^{-4}$ J

$\Rightarrow \quad v^2 = \frac{16 \times 10^{-4}}{0.01} = 16 \times 10^{-2}$ ...(i)

As it is given that KE of particle is equal to 8×10^{-4} J by the end of second revolution after the beginning of motion

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of particle. It means, its initial velocity (u) is 0 m/s at this moment.

$\because$ By Newton's 3rd equation of motion,

$v^2 = u^2 + 2a_t s$

$\Rightarrow v^2 = 2a_t S$ or $v^2 = 2a_t (4\pi r)$

($\because$ particle covers 2 revolutions)

$\Rightarrow a_t = \frac{v^2}{8\pi r} = \frac{16\times10^{-2}}{8\times3.14\times6.4\times10^{-2}}$

($\because$ from Eq. (i), $v^2 = 16\times10^{-2}$)

$\therefore a_t = 0.1\,\text{m/s}^2$

05 A particle moves from a point $(-2\hat{\mathbf{i}}+5\hat{\mathbf{j}})$ to $(4\hat{\mathbf{j}}+3\hat{\mathbf{k}})$ when a force of $(4\hat{\mathbf{i}}+3\hat{\mathbf{j}})$ N is applied. How much work has been done by the force? **[NEET 2016]**

(a) 8 J (b) 11 J (c) 5 J (d) 2 J

Ans. *(c)*

Position vectors of the particles are $\mathbf{r}_1 = -2\hat{\mathbf{i}}+5\hat{\mathbf{j}}$ and $\mathbf{r}_2 = 4\hat{\mathbf{j}}+3\hat{\mathbf{k}}$

$\therefore$ Displacement of the particle,

$\Delta\mathbf{s} = \mathbf{r}_2 - \mathbf{r}_1$

$= 4\hat{\mathbf{j}}+3\hat{\mathbf{k}} - (-2\hat{\mathbf{i}}+5\hat{\mathbf{j}}) = 2\hat{\mathbf{i}}-\hat{\mathbf{j}}+3\hat{\mathbf{k}}$

Force on the particle, $\mathbf{F} = 4\hat{\mathbf{i}}+3\hat{\mathbf{j}}$ N

$\therefore$ Work done, $W = \mathbf{F}\cdot\Delta\mathbf{s}$

$= (4\hat{\mathbf{i}}+3\hat{\mathbf{j}})\cdot(2\hat{\mathbf{i}}-\hat{\mathbf{j}}+3\hat{\mathbf{k}}) = 8-3 = 5\,\text{J}$

06 Two similar springs P and Q have spring constants K_P and K_Q, such that $K_P > K_Q$. They are stretched, first by the same amount (case a), then by the same force (case b). The work done by the springs W_P and W_Q are related as, in case (a) and case (b), respectively **[CBSE AIPMT 2015]**

(a) $W_b = W_a$; $W_b > W_a$
(b) $W_b = W_a$; $W_b = W_a$
(c) $W_P > W_Q$; $W_Q > W_P$
(d) $W_P < W_Q$; $W_Q < W_P$

Ans. *(c)*

Given, $K_P > K_Q$

In case (a), the elongation is same

i.e. $x_1 = x_2 = x$

So, $W_P = \frac{1}{2}K_P x^2$ and $W_Q = \frac{1}{2}K_Q x^2$

$\therefore \quad \frac{W_P}{W_Q} = \frac{K_P}{K_Q} > 1 \quad \Rightarrow W_P > W_Q$

In case (b), the spring force is same

i.e. $F_1 = F_2 = F$

So, $x_1 = \frac{F}{K_P}, x_2 = \frac{F}{K_Q}$

$\therefore \quad W_P = \frac{1}{2}K_P x_1^2 = \frac{1}{2}K_P\frac{F^2}{K_P^2} = \frac{1}{2}\frac{F^2}{K_P}$

and $W_Q = \frac{1}{2}K_Q x_2^2 = \frac{1}{2}K_Q\cdot\frac{F^2}{K_Q^2} = \frac{1}{2}\frac{F^2}{K_Q}$

$\therefore \quad \frac{W_P}{W_Q} = \frac{K_Q}{K_P} < 1$

$\Rightarrow \quad W_P < W_Q$

07 A block of mass 10 kg, moving in x-direction with a constant speed of 10 ms^{-1}, is subjected to a retarding force $F = 0.1x$ J/m during its travel from $x = 20$ m to 30 m. Its final KE will be **[CBSE AIPMT 2015]**

(a) 475 J (b) 450 J (c) 275 J (d) 250 J

Ans. *(a)*

From work-energy theorem,

Work done = Change in KE

$\Rightarrow \quad W = K_f - K_i$

$\Rightarrow \quad K_f = W + K_i = \int_{x_1}^{x_2} F x\,dx + \frac{1}{2}mv^2$

$= \int_{20}^{30} -0.1.x\,dx + \frac{1}{2}\times10\times10^2$

$= -0.1\left[\frac{x^2}{2}\right]_{20}^{30} + 500$

$= -0.05[30^2 - 20^2] + 500$

$= -0.05[900-400] + 500$

$\Rightarrow \quad K_f = -25 + 500 = 475\,\text{J}$

08 Two particles of masses m_1, m_2 move with initial velocities u_1 and u_2. On collision, one of the particles get excited to higher level, after absorbing energy ε. If final velocities of particles be v_1 and v_2, then we must have **[CBSE AIPMT 2015]**

(a) $m_1^2 u_1 + m_2^2 u_2 - \varepsilon = m_1^2 v_1 + m_2^2 v_2$

(b) $\frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 - \varepsilon$

(c) $\frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 - \varepsilon = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2$

(d) $\frac{1}{2}m_1^2 u_1^2 + \frac{1}{2}m_2^2 u_2^2 + \varepsilon = \frac{1}{2}m_1^2 v_1^2 + \frac{1}{2}m_2^2 v_2^2$

Ans. *(c)*

Total initial energy $= \frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2$

Since, after collision one particle absorb energy ε.

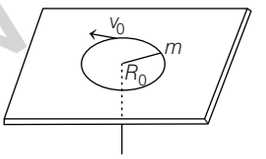
$\therefore$ Total final energy $= \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 + \varepsilon$

From conservation of energy,

$\frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 + \varepsilon$

$\Rightarrow \quad \frac{1}{2}m_1 u_1^2 + \frac{1}{2}m_2 u_2^2 - \varepsilon = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2$

09 A mass m moves in a circle on a smooth horizontal plane with velocity v_0 at a radius R_0. The mass is attached to a string which passes through a smooth hole in the plane as shown.



The tension in the string is increased gradually and finally m moves in a circle of radius $\frac{R_0}{2}$. The final value of the kinetic energy is **[CBSE AIPMT 2015]**

(a) mv_0^2 (b) $\frac{1}{4}mv_0^2$ (c) $2\,mv_0^2$ (d) $\frac{1}{2}mv_0^2$

Ans. *(c)*

Conserving angular momentum

$L_i = L_f$

$\Rightarrow \quad mv_0 R_0 = mv'\left(\frac{R_0}{2}\right) \Rightarrow v' = 2v_0$

So, final kinetic energy of the particle is

$K_f = \frac{1}{2}mv'^2 = \frac{1}{2}m(2v_0)^2$

$= 4\frac{1}{2}mv_0^2 = 2mv_0^2$

10 A ball is thrown vertically downwards from a height of 20m with an initial velocity v_0. It collides with the ground, loses 50% of its energy in collision and rebounds to the same height. The initial velocity v_0 is (Take, $g = 10\,\text{ms}^{-2}$) **[CBSE AIPMT 2015]**

(a) 14 ms^{-1} (b) 20 ms^{-1}
(c) 28 ms^{-1} (d) 10 ms^{-1}

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Ans. *(b)*

Suppose a ball rebounds with speed v,

$$v = \sqrt{2gh} = \sqrt{2 \times 10 \times 20}$$
$$= 20 \text{ m/s}$$

Energy of a ball just after rebound,

$$E = \frac{1}{2} mv^2 = 200 \text{ m}$$

As, 50% of energy loses in collision means just before collision energy is 400 m.

According to law of conservation of energy, we have

$$\frac{1}{2} mv_0^2 + mgh = 400 \text{ m}$$

$$\Rightarrow \quad \frac{1}{2} mv_0^2 + m \times 10 \times 20 = 400 \text{ m}$$

$$\Rightarrow \quad v_0 = 20 \text{ m/s}$$

11 A uniform force of $(3\hat{\mathbf{i}} + \hat{\mathbf{j}})$ N acts on a particle of mass 2 kg. Hence, the particle is displaced from position $(2\hat{\mathbf{i}} + \hat{\mathbf{k}})$ m to position $(4\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - \hat{\mathbf{k}})$ m. The work done by the force on the particle is **[NEET 2013]**

(a) 9 J (b) 6 J (c) 13 J (d) 15 J

Ans. *(a)*

Given, force $F = 3\hat{\mathbf{i}} + \hat{\mathbf{j}}$

$$\mathbf{r}_1 = (2\hat{\mathbf{i}} + \hat{\mathbf{k}}) \text{ m and } \mathbf{r}_2 = (4\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - \hat{\mathbf{k}}) \text{ m}$$

$$\therefore \quad \mathbf{s} = \mathbf{r}_2 - \mathbf{r}_1 = (4\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - \hat{\mathbf{k}}) - (2\hat{\mathbf{i}} + \hat{\mathbf{k}})$$
$$= (2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 2\hat{\mathbf{k}}) \text{ m}$$

$$\therefore W = \mathbf{F} \cdot \mathbf{s} = (3\hat{\mathbf{i}} + \hat{\mathbf{j}}) \cdot (2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 2\hat{\mathbf{k}})$$
$$= 3 \times 2 + 3 + 0 = 6 + 3 = 9 \text{ J}$$

12 The potential energy of a particle in a force field is $U = \frac{A}{r^2} - \frac{B}{r}$, where A and B are positive constants and r is the distance of particle from the centre of the field. For stable equilibrium, the distance of the particle is **[CBSE AIPMT 2012]**

(a) $B/2A$ (b) $2A/B$
(c) A/B (d) B/A

Ans. *(b)*

Given, the potential energy of a particle in a force field, $U = \frac{A}{r^2} - \frac{B}{r^1}$

For stable equilibrium, $F = -\frac{dU}{dr} = 0$

$$= \frac{dU}{dr} = -2Ar^{-3} + Br^{-2}$$

$$0 = -\frac{2A}{r^3} + \frac{B}{r^2} \qquad \left(\text{As } \frac{-dU}{dr} = 0\right)$$

or $\quad \frac{2A}{r} = B$

The distance of particle from the centre of the field

$$r = \frac{2A}{B}$$

13 The potential energy of a system increases, if work is done **[CBSE AIPMT 2011]**

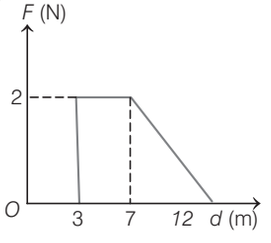
(a) by the system against a conservative force
(b) by the system against a non-conservative force
(c) upon the system by a conservative force
(d) upon the system by a non-conservative force

Ans. *(a)*

The potential energy of a system increases, if work is done by the system against a conservative force.

$$-\Delta U = W_{\text{conservative force}}$$

14 Force F on a particle moving in a straight line varies with distance d as shown in the figure. The work done on the particle during its displacement of 12 m is **[CBSE AIPMT 2011]**



(a) 21 J (b) 26 J
(c) 13 J (d) 18 J

Ans. *(c)*

Concept Work done is equal to area under the curve in F-d graph.

Work done = Area under (F-d) graph

$$= 2 \times (7 - 3) + \frac{1}{2} \times 2 \times (12 - 7)$$

$$= 8 + \frac{1}{2} \times 10 = 8 + 5 = 13 \text{ J}$$

15 A block of mass M is attached to the lower end of a vertical spring. The spring is hung from a ceiling and has force constant value k. The mass is released from rest with the spring initially unstretched. The maximum extension produced in the length of the spring will be **[CBSE AIPMT 2009]**

(a) Mg/k (b) $2\,Mg/k$
(c) $4\,Mg/k$ (d) $Mg/2k$

Ans. *(b)*

Let x be the extension in the spring.

Applying conservation of energy

$$Mgx - \frac{1}{2} kx^2 = 0 - 0$$

$$\Rightarrow \quad x = \frac{2\,Mg}{k}$$

16 A body of mass 1 kg is thrown upwards with a velocity 20 ms^{-1}. It momentarily comes to rest after attaining a height of 18 m. How much energy is lost due to air friction? (Take $g = 10\ ms^{-2}$) **[CBSE AIPMT 2009]**

(a) 20 J (b) 30 J (c) 40 J (d) 10 J

Ans. *(a)*

Concept Apply conservation of energy. Initially body posseses only kinetic energy and after attaining a height, the kinetic energy is zero.

Therefore, loss of energy = KE - PE

$$= \frac{1}{2} mv^2 - mgh$$
$$= \frac{1}{2} \times 1 \times 400 - 1 \times 18 \times 10$$
$$= 200 - 180 = 20 \text{ J}$$

17 300 J of work is done in sliding a 2 kg block up an inclined plane of height 10 m. Taking $g = 10\ m/s^2$, work done against friction is **[CBSE AIPMT 2006]**

(a) 200 J (b) 100 J
(c) zero (d) 1000 J

Ans. *(b)*

Net work done in sliding a body up to a height h on inclined plane

= Work done against gravitational force + Work done against frictional force

$$\Rightarrow \quad W = W_g + W_f \qquad \text{...(i)}$$

but $\quad W = 300 \text{ J}$

$$W_g = mgh$$
$$= 2 \times 10 \times 10 = 200 \text{ J}$$

Putting in Eq. (i), we get

$$300 = 200 + W_f$$

$$\Rightarrow \quad W_f = 300 - 200 = 100 \text{ J}$$

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18 A body of mass 3 kg is under a constant force, which causes a displacement s in metre in it, given by the relation $s=\frac{1}{3}t^2$, where t is in second. Work done by the force in 2 s is **[CBSE AIPMT 2006]**

(a) $\frac{5}{19}$ J (b) $\frac{3}{8}$ J

(c) $\frac{8}{3}$ J (d) $\frac{19}{5}$ J

Ans. *(c)*

Work done by the force = force × displacement

or $W = F \times s$ ...(i)

But from Newton's 2nd law, we have

Force = mass × acceleration

i.e. $F = ma$ ...(ii)

Hence, from Eqs. (i) and (ii), we get

$$W = mas = m\left(\frac{d^2s}{dt^2}\right)s \quad \left(\because a = \frac{d^2s}{dt^2}\right) \text{...(iii)}$$

Now, we have,

$$s = \frac{1}{3}t^2$$

$$\therefore \quad \frac{d^2s}{dt^2} = \frac{d}{dt}\left[\frac{d}{dt}\left(\frac{1}{3}t^2\right)\right]$$

$$= \frac{d}{dt} \times \left(\frac{2}{3}t\right)$$

$$= \frac{2}{3}\frac{dt}{dt} = \frac{2}{3}$$

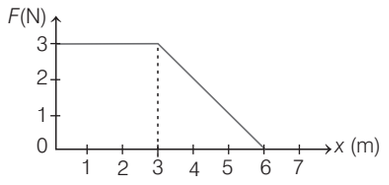
Hence, Eq. (iii) becomes

$$W = \frac{2}{3}ms = \frac{2}{3}m \times \frac{1}{3}t^2 = \frac{2}{9}mt^2$$

We have, $m = 3\text{ kg}, t = 2\text{ s}$

$$\therefore \quad W = \frac{2}{9} \times 3 \times (2)^2 = \frac{8}{3}\text{ J}$$

19 A force F acting on an object varies with distance x as shown here. The force is in newton and x is in metre. The work done by the force in moving the object from $x = 0$ to $x = 6$ m is **[CBSE AIPMT 2005]**



(a) 4.5 J (b) 13.5 J

(c) 9.0 J (d) 18.0 J

Ans. *(b)*

Work done in moving the object from $x = 0$ to $x = 6$ m, is given by area under the curve.

W = Area of square + area of triangle

$$= 3 \times 3 + \frac{1}{2} \times 3 \times 3$$

$$= 9 + 4.5 = 13.5\text{ J}$$

20 A bomb of mass 30 kg at rest explodes into two pieces of masses 18 kg and 12 kg. The velocity of 18 kg mass is 6 ms^{-1}. The kinetic energy of the other mass is **[CBSE AIPMT 2005]**

(a) 256 J (b) 486 J

(c) 524 J (d) 324 J

Ans. *(b)*

Applying conservation of linear momentum, we write,

$$m_1 u_1 = m_2 u_2$$

Here, $m_1 = 18\text{ kg}, \quad m_2 = 12\text{ kg}$

$u_1 = 6\text{ ms}^{-1}, u_2 = ?$

$$\therefore \quad 18 \times 6 = 12\, u_2$$

$$\Rightarrow \quad u_2 = \frac{18 \times 6}{12} = 9\text{ ms}^{-1}$$

Thus, kinetic energy of 12 kg mass

$$K_2 = \frac{1}{2}m_2 u_2^2$$

$$= \frac{1}{2} \times 12 \times (9)^2$$

$$= 6 \times 81 = 486\text{ J}$$

21 A particle of mass m_1 is moving with a velocity v_1 and another particle of mass m_2 is moving with a velocity v_2. Both of them have the same momentum, but their different kinetic energies are E_1 and E_2 respectively. If $m_1 > m_2$, then **[CBSE AIPMT 2004]**

(a) $E_1 < E_2$ (b) $\frac{E_1}{E_2} = \frac{m_1}{m_2}$

(c) $E_1 > E_2$ (d) $E_1 = E_2$

Ans. *(a)*

Kinetic energy is given by

$$E = \frac{1}{2}mv^2 = \frac{1}{2m}(mv)^2$$

but, mv = momentum of the particle = p

$$\therefore \quad E = \frac{p^2}{2m} \quad \text{or} \quad p = \sqrt{2mE}$$

Therefore, $\frac{p_1}{p_2} = \sqrt{\frac{m_1E_1}{m_2E_2}}$

but it is given that, $p_1 = p_2$

$$\therefore \quad m_1E_1 = m_2E_2$$

or $\frac{E_1}{E_2} = \frac{m_2}{m_1}$ ...(i)

Now, $m_1 > m_2$

or $\frac{m_1}{m_2} > 1$ ...(ii)

Thus, from Eqs. (i) and (ii), we get

$$\frac{E_1}{E_2} < 1 \quad \text{or} \quad E_1 < E_2$$

22 A ball of mass 2 kg and another of mass 4 kg are dropped together from a 60 ft tall building. After, a fall of 30 ft each towards earth, their respective kinetic energies will be in the ratio of **[CBSE AIPMT 2004]**

(a) $\sqrt{2}:1$ (b) 1 : 4

(c) 1 : 2 (d) $1:\sqrt{2}$

Ans. *(c)*

Concept Velocity of free falling body does not depend on its mass, it depends on the height from which it has been dropped.

$v_1 = v_2 = v$ at a 30 ft height from falling point.

Here, $m_1 = 2\text{ kg}, \quad m_2 = 4\text{ kg}$

Thus, $\frac{K_1}{K_2} = \frac{\frac{1}{2}m_1v^2}{\frac{1}{2}m_2v^2} = \frac{m_1}{m_2} = \frac{2}{4} = \frac{1}{2}$

23 If kinetic energy of a body is increased by 300%, then percentage change in momentum will be **[CBSE AIPMT 2002]**

(a) 100% (b) 150%

(c) 265% (d) 73.2%

Ans. *(a)*

Kinetic energy

$$K = \frac{1}{2m}(p^2) \quad \text{or} \quad p = \sqrt{2mK}$$

If kinetic energy of a body is increased by 300%, let its momentum becomes p'.

New kinetic energy

$$K' = K + \frac{300}{100}K = 4K \quad \begin{pmatrix}\text{initial KE} = K\\ \text{final KE} = K'\end{pmatrix}$$

Therefore, momentum is given by

$$p' = \sqrt{2m \times 4K} \quad \begin{pmatrix}\text{initial momentum} = p\\ \text{Final momentum} = p'\end{pmatrix}$$

$$= 2\sqrt{2mK} = 2p$$

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Hence, percentage change (increase) in momentum

$$\frac{\Delta p}{p}\times 100=\frac{p'-p}{p}\times 100$$
$$=\left(\frac{p'}{p}-1\right)\times 100$$
$$=\left(\frac{2p}{p}-1\right)\times 100$$
$$=100\%$$

24 A stone is thrown at an angle of 45° to the horizontal with kinetic energy K. The kinetic energy at the highest point is **[CBSE AIPMT 2001]**

(a) $\frac{K}{2}$ (b) $\frac{K}{\sqrt{2}}$
(c) K (d) zero

Ans. *(a)*

At the highest point

$$v_x=u\cos\theta$$
$$v_y=0$$
$$K_H=\frac{1}{2}mv_x^2$$

or $$K_H=\frac{1}{2}mu^2\cos^2\theta \quad ...(i)$$

Initial kinetic energy is

$$K=\frac{1}{2}mu^2 \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$K_H=K\cos^2\theta$$
$$=K\cos^2 45°$$
$$=K\times\left(\frac{1}{\sqrt{2}}\right)^2=\frac{K}{2}$$

25 A child is swinging a swing. Minimum and maximum heights of swing from the earth's surface are 0.75 m and 2 m respectively. The maximum velocity of this swing is **[CBSE AIPMT 2001]**

(a) 5 m/s (b) 10 m/s
(c) 15 m/s (d) 20 m/s

Ans. *(a)*

From energy conservation

$$\frac{1}{2}mv_{max}^2=mg(H_2-H_1)$$

Here, H_1 = minimum height of swing from the earth's surface

= 0.75 m

H_2 = maximum height of swing from earth's surface

= 2 m

$$\therefore \quad \frac{1}{2}mv_{max}^2=mg(2-0.75)$$

or $$v_{max}=\sqrt{2\times 10\times 1.25}$$
$$=\sqrt{25}=5 \text{ m/s}$$

26 Two bodies with kinetic energies in the ratio 4 : 1 are moving with equal linear momentum. The ratio of their masses is **[CBSE AIPMT 1999]**

(a) 1 : 2 (b) 1 : 1 (c) 4 : 1 (d) 1 : 4

Ans. *(d)*

As we know that, relation between kinetic energy and momentum is given by

$$KE=\frac{p^2}{2m}$$

If $p_1=p_2$ for two bodies

So, $$KE_1\propto\frac{1}{m_1}$$

and $$KE_2\propto\frac{1}{m_2}$$

Therefore, ratio of two masses is given by

$$\frac{m_1}{m_2}=\frac{KE_2}{KE_1}=\frac{1}{4} \qquad \left[\because \frac{KE_1}{KE_2}=\frac{4}{1}\right]$$

27 A force acts on a 3.0 g particle in such a way that the position of the particle as a function of time is given by $x=3t-4t^2+t^3$, where x is in metre and t in second. The work done during the first 4 s is **[CBSE AIPMT 1998]**

(a) 570 mJ (b) 450 mJ
(c) 490 mJ (d) 528 mJ

Ans. *(d)*

Given, $x=3t-4t^2+t^3$

So, velocity

$$v=\frac{dx}{dt}=3-8t+3t^2$$

At $t=0$ s, $v_1=3-0+0=3$ m/s

At $t=4$ s, $v_2=3-8\times 4+3\times 4^2$
$=3-32+48=19$ m/s

Now, work done during $t=0$ to $t=4$ s
= gain in kinetic energy

$$=\frac{1}{2}mv_2^2-\frac{1}{2}mv_1^2=\frac{1}{2}m(v_2^2-v_1^2)$$
$$=\frac{1}{2}\times 3\times 10^{-3}[(19)^2-(3)^2]$$

[Using, $a^2-b^2=(a+b)(a-b)$]

$$=1.5\times 10^{-3}\times[(19+3)(19-3)]$$
$$=1.5\times 10^{-3}\times 22\times 16$$
$$=528\times 10^{-3}\text{ J}=528\text{ mJ}$$

28 A rubber ball is dropped from a height of 5 m on a planet where the acceleration due to gravity is not known. On bouncing it rises to 1.8 m. The ball loses its velocity on bouncing by a factor of **[CBSE AIPMT 1998]**

(a) 16/25 (b) 2/5
(c) 3/5 (d) 9/25

Ans. *(b)*

Potential energy = Kinetic energy

i.e. $$mgh=\frac{1}{2}mv^2 \quad \Rightarrow \quad v=\sqrt{2gh}$$

If h_1 and h_2 are the initial and final heights, then

$$v_1=\sqrt{2gh_1},\ v_2=\sqrt{2gh_2}$$

Loss in velocity

$$\Delta v=v_1-v_2=\sqrt{2gh_1}-\sqrt{2gh_2}$$

∴ Fractional loss in velocity

$$=\frac{\Delta v}{v_1}=\frac{\sqrt{2gh_1}-\sqrt{2gh_2}}{\sqrt{2gh_1}}=1-\sqrt{\frac{h_2}{h_1}}$$

Substituting the values, we have

$$\therefore \quad \frac{\Delta v}{v_1}=1-\sqrt{\frac{1.8}{5}}=1-\sqrt{0.36}=1-0.6$$
$$=0.4=\frac{2}{5}$$

29 If the momentum of a body is increased by 50%, then the percentage increase in its kinetic energy is **[CBSE AIPMT 1995]**

(a) 50% (b) 100% (c) 125% (d) 200%

Ans. *(c)*

Let p_1 be the initial momentum and p_2 be the inversed momentum

So, $$p_2=\frac{150}{100}p_1$$

i.e. $$mv_2=\frac{15}{10}mv_1 \qquad \left(\begin{matrix}p_1=mv_1\\ p_2=mv_2\end{matrix}\right)$$

or $$v_2=\frac{15}{10}v_1$$

Now, $$\frac{E_2}{E_1}=\frac{\frac{1}{2}mv_2^2}{\frac{1}{2}mv_1^2}=\left(\frac{v_2}{v_1}\right)^2=\left(\frac{15}{10}\right)^2=\frac{225}{100}$$

Clearly, $E_2>E_1$

So, percentage increase in KE

$$=\frac{(E_2-E_1)}{E_1}\times 100$$
$$=\left(\frac{225}{100}-1\right)\times 100=125\%$$

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30 The KE acquired by a mass m in travelling a certain distance d, starting from rest, under the action of a constant force is directly proportional to **[CBSE AIPMT 1994]**

(a) m
(b) $\sqrt{m}$
(c) $\frac{1}{\sqrt{m}}$
(d) Independent of m

Ans. *(d)*

Kinetic energy acquired by the body

$$= \frac{1}{2} mv^2 .$$

If body starts from rest, then final velocity achieved by body in displacement d is

$$v^2 = 0 + 2ad = 2ad$$

but $$a = \frac{F}{m}$$

$$\therefore \quad v^2 = 2\left(\frac{F}{m}\right)d$$

Hence, $$KE = \frac{1}{2} m \times 2\left(\frac{F}{m}\right)d = Fd$$

or KE acquired = Work done

$$= F \times d = \text{constant}$$

So, KE acquired is independent of mass m.

31 Two masses 1 g and 9 g are moving with equal kinetic energies. The ratio of the magnitudes of their respective linear momenta is **[CBSE AIPMT 1993]**

(a) 1 : 9 (b) 9 : 1
(c) 1 : 3 (d) 3 : 1

Ans. *(c)*

Given, $KE_1 = KE_2$

$$\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2$$

or $$\frac{v_2^2}{v_1^2} = \frac{m_1}{m_2} \quad \text{or} \quad \frac{v_2}{v_1} = \sqrt{\frac{m_1}{m_2}}$$

As, $p_2 = m_2 v_2$ and $p_1 = m_1 v_1$

$$\therefore \quad \frac{p_2}{p_1} = \frac{m_2 v_2}{m_1 v_1} = \frac{m_2}{m_1}\sqrt{\frac{m_1}{m_2}} = \sqrt{\frac{m_2^2 m_1}{m_1^2 m_2}}$$

$$\frac{p_2}{p_1} = \sqrt{\frac{m_2}{m_1}}$$

or $$\frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}}$$

Here, $m_1 = 1\,g$, $m_2 = 9\,g$

$$\therefore \quad \frac{p_1}{p_2} = \sqrt{\frac{1}{9}} = \frac{1}{3}$$

Alternative

The relation between KE and p is given by

$$KE = \frac{p^2}{2m}$$

$$\Rightarrow \quad p^2 = 2mKE$$

$$\Rightarrow \quad p = \sqrt{2mKE}$$

If KE of two bodies are equal.

So, $$p_1 \propto \sqrt{m_1}$$

and $$p_2 \propto \sqrt{m_2}$$

$$\Rightarrow \quad \frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}} = \sqrt{\frac{1}{9}} = \frac{1}{3}$$

32 A position dependent force $F = (7 - 2x + 3x^2)\,N$, acts on a small body of mass 2 kg and displaces it from $x = 0$ to $x = 5$ m. Work done in joule is **[CBSE AIPMT 1992]**

(a) 35 (b) 70
(c) 135 (d) 270

Ans. *(c)*

Work done by a variable force F in displacement from $x = x_1$ to $x = x_2$ is given by

$$W = \int_{x_1}^{x_2} F(dx)$$

Given, $x_1 = 0$, $x_2 = 5$

$$F = (7 - 2x + 3x^2)\,N$$

$$\therefore \quad W = \int_0^5 (7 - 2x + 3x^2)\,dx$$

$$= [7x - x^2 + x^3]_0^5$$

$$= [7 \times 5 - (5)^2 + (5)^3]$$

$$= [35 - 25 + 125] = 135\,J$$

33 A bullet of mass 10 g leaves a rifle at an initial velocity of 1000 m/s and strikes the earth at the same level with a velocity of 500 m/s. The work done in joule to overcome the resistance of air will be **[CBSE AIPMT 1989]**

(a) 375 (b) 3750 (c) 5000 (d) 500

Ans. *(b)*

According to work-energy theorem, work done by a force in displacing a body measures the change in kinetic energy of the body or work done by a force is equal to change in KE of the body.

or $$W = \Delta E$$

$$= \text{final KE} - \text{initial KE}$$

$$= \frac{1}{2} mv^2 - \frac{1}{2} mu^2$$

Given, $v = 1000\,m/s$, $m = 10\,g$

$u = 500\,m/s$, $= 0.01\,kg$

Putting the values of m, u, v

$$\therefore \quad W = \frac{1}{2} \times 0.01\,[(1000)^2 - (500)^2]$$

$$= 3750\,J$$

TOPIC 2
Work Energy Theorem, Power and Verticle Circle

34 Water falls from a height of 60 m at the rate of 15 kg/s to operate a turbine. The losses due to frictional force are 10% of the input energy. How much power is generated by the turbine? ($g = 10\,m/s^2$) **[NEET 2021]**

(a) 10.2 kW (b) 8.1 kW
(c) 12.3 kW (d) 7.0 kW

Ans. *(b)*

Given, the flow rate of the water,

$$\frac{m}{t} = 15\,kg/s$$

The height of the water fall, $h = 60$ m

Loss due to frictional force = 10%

The power used in the turbine

$= (100 - 10)\,\% = 90\%$

The acceleration due to gravity,

$g = 10\,m/s^2$

We know that, power generated by the turbine

= change in potential energy $= 0.90\,\frac{mgh}{t}$

$= 0.90 \times 15 \times 10 \times 60 = 8100\,W = 8.1\,kW$

35 A point mass m is moved in a vertical circle of radius r with the help of a string. The velocity of the mass is $\sqrt{7gr}$ at the lowest point. The tension in the string at the lowest point is **[NEET (Oct.) 2020]**

(a) 6 mg (b) 7 mg (c) 8 mg (d) 1 mg

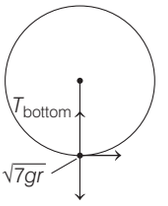
Ans. *(c)*

Velocity of point mass in vertical circle at lowest point, $V_l = \sqrt{7gr}$

$$\therefore \quad V_l = \sqrt{7gr} > \sqrt{5gr}$$

Hence, point mass will have completed the vertical circular path.

We know that,



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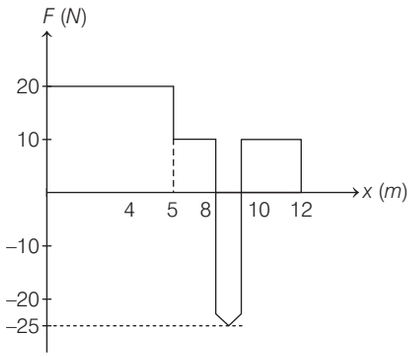
$$T_{bottom} - mg = \frac{mv^2}{r} = \frac{m}{r}(\sqrt{7gr})^2$$

$$\Rightarrow \quad T_{bottom} - mg = 7mg$$

$$\Rightarrow \quad T_{bottom} = 8mg$$

36 An object of mass 500 g, initially at rest acted upon by a variable force whose X component varies with X in the manner shown. The velocities of the object a point $X = 8$ m and $X = 12$ m, would be the respective values of (nearly)

[NEET (Odisha) 2019]



(a) 18 m/s and 24.4 m/s
(b) 23 m/s and 24.4 m/s
(c) 23 m/s and 20.6 m/s
(d) 18 m/s and 20.6 m/s

Ans. *(c)*

The area under the force displacement curve give the amount of work done.

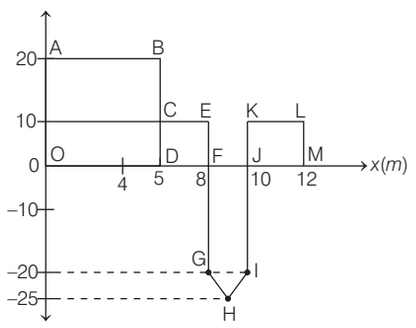
From work-energy theorem,

$$W = \Delta KE \qquad ...(i)$$

$\therefore$ At $x = 8$ m,

$W =$ Area $ABDO +$ Area $CEFD$

$= 20 \times 5 + 10 \times 3 = 130$ J



Using Eq. (i)

$$\Rightarrow \quad 130 = \frac{1}{2}mv^2 = \frac{1}{2} \times \frac{500}{1000}v^2$$

$$\Rightarrow \quad v = 2\sqrt{130} = 22.8\,\text{ms}^{-1} \approx 23\,\text{ms}^{-1}$$

At $x = 12$ m

$W =$ Area $ABDO +$ Area $CEFD +$ Area $FGHIJ +$ Area $KLMJ$

$$W = 20 \times 5 + 10 \times 3 + (-20 \times 2) + \left(\frac{1}{2} \times -5 \times 2\right) + 10 \times 2$$

[$\because$ Area FGHIJ = Area FGIJ + Area GHI]

$= 100 + 30 - 40 - 5 + 20 = 105$ J

Using Eq. (i)

$$\therefore \quad 105 = \frac{1}{2} \times \frac{1}{2} \times v^2$$

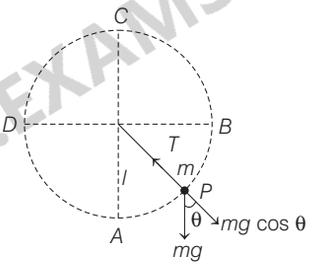
$$\Rightarrow \quad v = 2\sqrt{105} \simeq 20.6\,\text{ms}^{-1}$$

37 A mass m is attached to a thin wire and whirled in a vertical circle. The wire is most likely to break when: **[NEET (National) 2019]**

(a) the wire is horizontal
(b) the mass is at the lowest point
(c) inclined at an angle of 60° from vertical
(d) the mass is at the highest point

Ans. *(b)*

Let the mass m which is attached to a thin wire and is whirled in a vertical circle is shown in the figure below.



The tension in the string at any point P be T.

According to Newton's law of motion, In equilibrium, net force towards the centre = centripetal force

$$\Rightarrow \quad T - mg\cos\theta = \frac{mv^2}{l}$$

Here, l = length of wire and v = linear velocity of the particle whirling in a circle.

$$\Rightarrow \quad T = mg\cos\theta + \frac{mv^2}{l}$$

At $A, \theta = 0° \Rightarrow T_A = mg + \frac{mv^2}{l}$

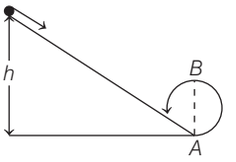
At $B, \theta = 90° \Rightarrow T_B = \frac{mv^2}{l}$

At $C, \theta = 180° \Rightarrow T_C = -mg + \frac{mv^2}{l}$

At $D, \theta = 90° \Rightarrow T_D = T_B = \frac{mv^2}{l}$

So, from the above analysis, it can be concluded that the tension is maximum at A i.e. the lowest point of circle, So chance of breaking is maximum.

38 A body initially at rest and sliding along a frictionless track from a height h (as shown in the figure) just completes a vertical circle of diameter $AB = D$. The height h is equal to **[NEET 2018]**



(a) $\frac{7}{5}D$ (b) D
(c) $\frac{3}{2}D$ (d) $\frac{5}{4}D$

Ans. *(d)*

If a body is moving on a frictionless surface, then its total mechanical energy remains conserved.

According to the conservation of mechanical energy,

$$(TE)_{initial} = (TE)_{final}$$

$$\Rightarrow \quad (KE)_i + (PE)_i = (KE)_f + (PE)_f$$

$$0 + mgh = \frac{1}{2}mv_A^2 + 0$$

$$\Rightarrow \quad gh = \frac{v_A^2}{2} \text{ or } h = \frac{v_A^2}{2g} \qquad ...(i)$$

In order to complete the vertical circle, the velocity of the body at point A should be

$$v_A = v_{min} = \sqrt{5gR}$$

where, R is the radius of the body.

Here, $R = \frac{AB}{2} = \frac{D}{2}$

$$\Rightarrow \quad v_{min} = v_A = \sqrt{\frac{5}{2}gD}$$

Substituting the value of v_A in Eq. (i), we get

$$h = \frac{\left(\sqrt{\left(\frac{5}{2}gD\right)}\right)^2}{2g}$$

$$= \frac{5gD}{2 \times 2g} = \frac{5}{4}D$$

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39 Consider a drop of rain water having mass 1 g falling from a height of 1 km. It hits the ground with a speed of 50 m/s. Take g constant with a value of 10 m/s^2. The work done by the (i) gravitational force and the (ii) resistive force of air is **[NEET 2017]**

(a) (i) –10 J, (ii) – 8.25 J
(b) (i) 1.25 J, (ii) – 8.25 J
(c) (i) 100 J, (ii) 8.75 J
(d) (i) 10 J, (ii) – 8.75 J

Ans. *(d)*

By work-KE theorem, we have change in KE = work done by all of the forces.

Work done by gravitational force,

$$W_g = mgh = 10^{-3} \times 10 \times 1 \times 10^3 = 10\ \text{J}$$

Now, from work-KE theorem, we have

$$\Delta K = W_{\text{gravity}} + W_{\text{air resistance}}$$

$$\Rightarrow \quad \frac{1}{2} \times mv^2 = mgh + W_{\text{air resistance}}$$

$$\Rightarrow W_{\text{air resistance}} = \frac{1}{2} mv^2 - mgh$$

$$= 10^{-3}\left(\frac{1}{2} \times 50 \times 50 - 10 \times 10^3\right)$$

$$= -8.75\ \text{J}$$

40 A body of mass 1 kg begins to move under the action of a time dependent force $\mathbf{F} = (2t\,\hat{\mathbf{i}} + 3t^2\,\hat{\mathbf{j}})$ N, where $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$ are unit vectors along X and Y axes. What power will be developed by the force at the time (t)? **[NEET 2016]**

(a) $(2t^2 + 4t^4)$ W (b) $(2t^3 + 3t^4)$ W
(c) $(2t^3 + 3t^5)$ W (d) $(2t + 3t^3)$ W

Ans. *(c)*

According to question, a body of mass 1 kg begins to move under the action of time dependent force,

$$\mathbf{F} = (2t\hat{\mathbf{i}} + 3t^2\hat{\mathbf{j}})\ N$$

where $\hat{\mathbf{i}}$ and $\hat{\mathbf{j}}$ are unit vectors along X and Y-axes.

$$\because \quad \mathbf{F} = m\mathbf{a} \quad \Rightarrow \quad \mathbf{a} = \frac{\mathbf{F}}{m}$$

$$\Rightarrow \quad \mathbf{a} = \frac{(2t\hat{\mathbf{i}} + 3t^2\hat{\mathbf{j}})}{1} \qquad (\because\ m = 1\,\text{kg})$$

$$\Rightarrow \quad \mathbf{a} = (2t\hat{\mathbf{i}} + 3t^2\hat{\mathbf{j}})\ \text{m/s}^2$$

$$\because \text{ acceleration, } a = \frac{dv}{dt}$$

$$\Rightarrow \quad dv = a\,dt \qquad \ldots(i)$$

Integrating both sides, we get

$$\int dv = \int a\,dt = \int (2t\hat{\mathbf{i}} + 3t^2\hat{\mathbf{j}})\,dt$$

$$\mathbf{v} = t^2\hat{\mathbf{i}} + t^3\hat{\mathbf{j}}$$

$\because$ Power developed by the force at the time t will be given as

$$P = \mathbf{F} \cdot \mathbf{v} = (2t\hat{\mathbf{i}} + 3t^2\hat{\mathbf{j}}) \cdot (t^2\hat{\mathbf{i}} + t^3\hat{\mathbf{j}})$$

$$= (2t.t^2 + 3t^2.t^3)$$

$$P = (2t^3 + 3t^5)\ \text{W}$$

41 What is the minimum velocity with which a body of mass m must enter a vertical loop of radius R so that it can complete the loop? **[NEET 2016]**

(a) $\sqrt{2gR}$ (b) $\sqrt{3gR}$ (c) $\sqrt{5gR}$ (d) $\sqrt{gR}$

Ans. *(c)*

According to question, we have

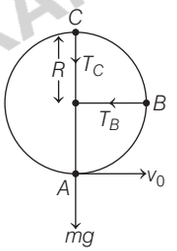
Let the tension at point A be T_A. So, from Newton's second law

$$T_A - mg = \frac{mv_c^2}{R}$$

Energy at point $A = \frac{1}{2} mv_0^2$ ...(i)

Energy at point C is

$$\frac{1}{2} mv_c^2 + mg \times 2R \qquad \ldots(ii)$$



Applying Newton's 2nd law at point C

$$T_c + mg = \frac{mv_c^2}{R}$$

To complete the loop $T_c \geq 0$

So, $mg = \frac{mv_c^2}{R}$

$$\Rightarrow \quad v_c = \sqrt{gR} \qquad \ldots(iii)$$

From Eqs. (i) and (ii) by conservation of energy

$$\frac{1}{2} mv_0^2 = \frac{1}{2} mv_c^2 + 2mgR$$

$$\Rightarrow \quad \frac{1}{2} mv_0^2 = \frac{1}{2} mgR + 2mgR \times 2$$

$$(\because\ v_c = \sqrt{gR})$$

$$\Rightarrow \quad v_0^2 = gR + 4gR$$

$$\Rightarrow \quad v_0 = \sqrt{5gR}$$

42 A particle of mass m is driven by a machine that delivers a constant power k watts. If the particle starts from rest, the force on the particle at time t is **[CBSE AIPMT 2015]**

(a) $\sqrt{\frac{mk}{2}}\, t^{-1/2}$ (b) $\sqrt{mk}\ t^{-1/2}$
(c) $\sqrt{2mk}\ t^{-1/2}$ (d) $\frac{1}{2}\sqrt{mk}\ t^{-1/2}$

Ans. *(a)*

As the machine delivers a constant power

So $F.v$ = constant = k (watts)

$$\Rightarrow \quad m\frac{dv}{dt} \cdot v = k \quad \Rightarrow \quad \int v dv = \frac{k}{m}\int dt$$

$$\Rightarrow \quad \frac{v^2}{2} = \frac{k}{m}t \Rightarrow v = \sqrt{\frac{2k}{m}t}$$

Now, force on the particle is given by

$$F = m\frac{dv}{dt} = m\frac{d}{dt}\left(\frac{2kt}{m}\right)^{\frac{1}{2}}$$

$$= \sqrt{2km}.\left(\frac{1}{2}t^{-\frac{1}{2}}\right) = \sqrt{\frac{mk}{2}} \cdot t^{-\frac{1}{2}}$$

43 The heart of a man pumps 5 L of blood through the arteries per minute at a pressure of 150 mm of mercury. If the density of mercury be 13.6×10^3 kg / m^3 and $g = 10$ m / s^2, then the power of heart in watt is **[CBSE AIPMT 2015]**

(a) 1.70 (b) 2.35 (c) 3.0 (d) 1.50

Ans. *(a)*

Given, pressure = 150 mm of Hg

Pumping rate of heart of a man

$$= \frac{dV}{dt} = \frac{5 \times 10^{-3}}{60}\ \text{m}^3/\text{s}$$

Power of heart $= P \cdot \frac{dV}{dt} = \rho gh \cdot \frac{dV}{dt}$

$$[p = \rho gh]$$

$$\frac{(13.6 \times 10^3\ \text{kg/m}^3)(10 \times 0.15 \times 5 \times 10^{-3})}{60}$$

$$= 1.70\ \text{W}$$

44 An engine pumps water through a hose pipe. Water passes through the pipe and leaves it with a velocity of 2 m s^{-1}. The mass per unit length of water in the pipe is 100 kg m^{-1}. What is the power of the engine? **[CBSE AIPMT 2010]**

(a) 400 W (b) 200 W
(c) 100 W (d) 800 W

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Ans. *(d)*

Given, Velocity of water $v = 2\ \text{m/s}$

Mass per unit length of water in the pipe

$= 100\ \text{kg/m}$

So, power = (mass per unit length of water in pipe) $\times v^3$

$= \frac{m}{l} \times v^3$

$= 100 \times 2 \times 2 \times 2 = 800\ \text{W}$

45 An engine pumps water continuously through a hose. Water leaves the hose with a velocity v and m is the mass per unit length of the water jet. What is the rate at which kinetic energy is imparted to water ? **[CBSE AIPMT 2009]**

(a) $\frac{1}{2}mv^3$ (b) mv^3

(c) $\frac{1}{2}mv^2$ (d) $\frac{1}{2}m^2v^2$

Ans. *(a)*

As m is the mass per unit length, then

rate of mass per second $= \frac{mx}{t} = mv$

$\therefore$ Rate of KE $= \frac{1}{2}(mv)v^2 = \frac{1}{2}mv^3$

46 Water falls from a height of 60 m at the rate of 15 kg/s to operate a turbine. The losses due to frictional forces are 10% of energy. How much power is generated by the turbine ? $(\text{Take} g = 10\,\text{m/s}^2)$ **[CBSE AIPMT 2008]**

(a) 8.1 kW (b) 10.2 kW

(c) 12.3 kW (d) 7.0 kW

Ans. *(a)*

$P_{\text{generated}} = P_{\text{input}} \times \frac{90}{100} = \frac{mgh}{t} \times \frac{90}{100}$

$= \frac{15 \times 10 \times 60}{1} \times \frac{90}{100} = 8.1\ \text{kW}$

47 A stone is tied to a string of length l and is whirled in a vertical circle with the other end of the string as the centre. At a certain instant of time, the stone is at its lowest position and has a speed u. The magnitude of the change in velocity as it reaches a position where the string is horizontal (g being acceleration due to gravity) is **[CBSE AIPMT 2004]**

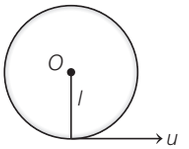
(a) $\sqrt{2(u^2 - gl)}$ (b) $\sqrt{u^2 - gl}$

(c) $u - \sqrt{u^2 - 2gl}$ (d) $\sqrt{2gl}$

Ans. *(a)*

When stone is at its lowest position, it has only kinetic energy, given by

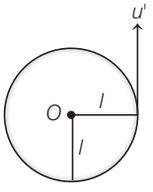
$K = \frac{1}{2}mu^2$



At the horizontal position, it has energy

$E = U + K = \frac{1}{2}mu'^2 + mgl$

According to conservation of mechanical energy, $K = E$



$\therefore \quad \frac{1}{2}mu^2 = \frac{1}{2}mu'^2 + mgl$

or $\frac{1}{2}mu'^2 = \frac{1}{2}mu^2 - mgl$

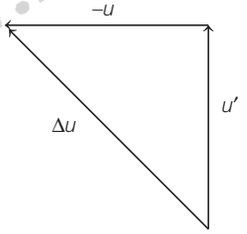
or $u'^2 = u^2 - 2gl$

or $u' = \sqrt{u^2 - 2gl}$ ...(i)

So, the magnitude of change in velocity

$|\Delta \mathbf{u}| = |\mathbf{u}' - \mathbf{u}|$

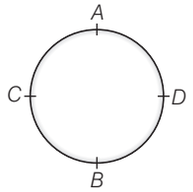
$= \sqrt{u'^2 + u^2 + 2u'u\cos 90°}$



$|\Delta \mathbf{u}| = \sqrt{u'^2 + u^2} = \sqrt{2(u^2 - gl)}$

[from Eq. (i)]

48 A stone is attached to one end of a string and rotated in a vertical circle. If string breaks at the position of maximum tension, it will break at **[CBSE AIPMT 2000]**

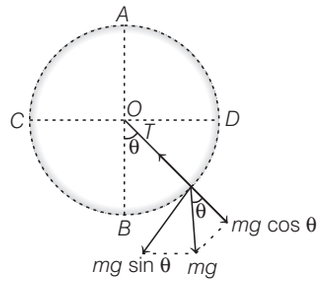


(a) A (b) B (c) C (d) D

Ans. *(b)*

When string makes an angle θ with the vertical in a vertical circle, then balancing the force we get

$T - mg\cos\theta = \frac{mv^2}{l}$



or $T = mg\cos\theta + \frac{mv^2}{l}$

Tension is maximum when $\cos\theta = +1$

i.e. $\theta = 0$

Thus, θ is zero at lowest point B. At this point tension is maximum. So, string will break at point B.

49 How much water a pump of 2 kW can raise in one minute to a height of 10 m? (Take $g = 10\ \text{m/s}^2$) **[CBSE AIPMT 1990]**

(a) 1000 L (b) 1200 L (c) 100 L (d) 2000 L

Ans. *(b)*

Power of a body is defined as the rate at which the body can do the work, i.e.

$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{W}{t}$

Given, power, $P = 2\ \text{kW} = 2000\ \text{W}$

$W = Mgh = M \times 10 \times 10 \quad [\because g = 10\ \text{m/s}^2]$

$= 100\ M$

Time, $t = 60\ \text{s}$

$\therefore \quad 2000 = \frac{100M}{60}$

$\therefore \quad M = 1200\ \text{kg}$ and $V = 1200\ \text{L}$

TOPIC 3
Collision

50 An object flying in air with velocity $(20\hat{\mathbf{i}} + 25\hat{\mathbf{j}} - 12\hat{\mathbf{k}})$ suddenly breaks in two pieces whose masses are in the ratio 1 : 5. The smaller mass flies off with a velocity $(100\hat{\mathbf{i}} + 35\hat{\mathbf{j}} + 8\hat{\mathbf{k}})$. The velocity of the larger piece will be **[NEET (Odisha) 2019]**

(a) $4\hat{\mathbf{i}} + 23\hat{\mathbf{j}} - 8\hat{\mathbf{k}}$ (b) $-100\hat{\mathbf{i}} - 35\hat{\mathbf{j}} - 8\hat{\mathbf{k}}$

(c) $20\hat{\mathbf{i}} + 15\hat{\mathbf{j}} - 80\hat{\mathbf{k}}$ (d) $-20\hat{\mathbf{i}} - 15\hat{\mathbf{j}} - 80\hat{\mathbf{k}}$

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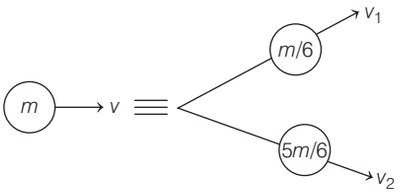
Ans. *(a)*

Let m be the mass of an object flying with velocity v in air. When it split into two pieces of masses in ratio 1 : 5, the mass of smaller piece is $m/6$ and of bigger piece is $\frac{5m}{6}$.

This situation can be interpreted diagrammatically as below



As the object breaks in two pieces, so the momentum of the system will remains conserved i.e. the total momentum (before breaking) = total momentum (after breaking)

$$m\mathbf{v} = \frac{m}{6}\mathbf{v_1} + \frac{5m}{6}\mathbf{v_2}$$

$$\Rightarrow \quad \mathbf{v} = \frac{\mathbf{v}_1}{6} + \frac{5\mathbf{v}_2}{6}$$

Here, $\mathbf{v} = 20\hat{\mathbf{i}} + 25\hat{\mathbf{j}} - 12\hat{\mathbf{k}}$

$$\mathbf{v}_1 = 100\hat{\mathbf{i}} + 35\hat{\mathbf{j}} + 8\hat{\mathbf{k}}$$

$$\Rightarrow \ 20\hat{\mathbf{i}} + 25\hat{\mathbf{j}} - 12\hat{\mathbf{k}} = \frac{(100\hat{\mathbf{i}} + 35\hat{\mathbf{j}} + 8\hat{\mathbf{k}})}{6} + \frac{5\mathbf{v}_2}{6}$$

$$\Rightarrow \ (120\hat{\mathbf{i}} + 150\hat{\mathbf{j}} - 72\hat{\mathbf{k}}) = (100\hat{\mathbf{i}} + 35\hat{\mathbf{j}} + 8\hat{\mathbf{k}}) + 5\mathbf{v}_2$$

$$\Rightarrow \quad \mathbf{v}_2 = \frac{1}{5}(20\hat{\mathbf{i}} + 115\hat{\mathbf{j}} - 80\hat{\mathbf{k}}) = 4\hat{\mathbf{i}} + 23\hat{\mathbf{j}} - 16\hat{\mathbf{k}}$$

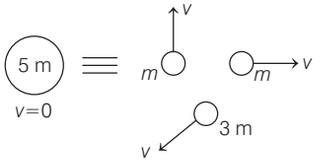
51 A particle of mass 5 m at rest suddenly breaks on its own into three fragments. Two fragments of mass m each move along mutually perpendicular direction with each speed v. The energy released during the process is **[NEET (Odisha) 2019]**

(a) $\frac{3}{5}mv^2$ (b) $\frac{5}{3}mv^2$

(c) $\frac{3}{2}mv^2$ (d) $\frac{4}{3}mv^2$

Ans. *(d)*

The particle of mass 5m breaks in three fragments of mass m, m and 3m respectively. Two fragments of mass m each, move in perpendicular direction with velocity v and the left fragment will move in a direction with velocity $\mathbf{v}'$ such that the total momentum of the system must remain conserved.



By law of conservation of momentum,

$$5m \times 0 = mv\hat{\mathbf{i}} + mv\hat{\mathbf{j}} + 3m\mathbf{v}'$$

$$\Rightarrow \quad \mathbf{v}' = -\frac{v}{3}\hat{\mathbf{i}} - \frac{v}{3}\hat{\mathbf{j}}$$

$$\therefore \quad |\mathbf{v}'| = \sqrt{\left(-\frac{v}{3}\right)^2 + \left(-\frac{v}{3}\right)^2} = \frac{v\sqrt{2}}{3}$$

$\therefore$ Energy released

$$E = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + \frac{1}{2} \times 3m\left(\frac{v\sqrt{2}}{3}\right)^2$$

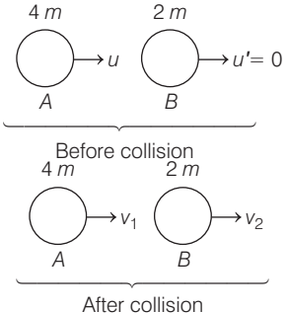
$$= mv^2 + \frac{mv^2}{3} = \frac{4}{3}mv^2$$

52 Body A of mass $4m$ moving with speed u collides with another body B of mass $2m$, at rest. The collision is head on and elastic in nature. After the collision the fraction of energy lost by the colliding body A is **[NEET (National) 2019]**

(a) $\frac{8}{9}$ (b) $\frac{4}{9}$ (c) $\frac{5}{9}$ (d) $\frac{1}{9}$

Ans. *(a)*

In head-on elastic collision, momentum and kinetic energy before and after the collision is conserved. The given situation of collision can be drawn as



Applying conservation of linear momentum,

Initial momentum of system = Final momentum of system

$$\Rightarrow \quad (4m)u + (2m)u' = (4m)v_1 + (2m)v_2$$

$$4mu = 4mv_1 + 2mv_2$$

or $\quad 2u = 2v_1 + v_2 \quad \ldots(i)$

The kinetic energy of A before collision is

$$\mathrm{KE}_A = \frac{1}{2}(4m)u^2 = 2mu^2$$

Kinetic energy of B before collision,

$$\mathrm{KE}_B = 0$$

The kinetic energy of A after collision is

$$\mathrm{KE}'_A = \frac{1}{2}(4m)v_1^2 = 2mv_1^2$$

Kinetic energy of B after collision,

$$\mathrm{KE}'_B = \frac{1}{2}(2m)v_2^2 = mv_2^2$$

As, Initial kinetic energy of the system = Final kinetic energy of the system

$$\Rightarrow \mathrm{KE}'_A + \mathrm{KE}'_B = \mathrm{KE}'_A + \mathrm{KE}'_B$$

$$2mu^2 + 0 = 2mv_1^2 + mv_2^2$$

$$2mu^2 = 2mv_1^2 + mv_2^2 \text{ or } 2u^2 = 2v_1^2 + v_2^2 \quad \ldots(ii)$$

Solving Eqs. (i) and (ii), we get

$$v_1 = \frac{1}{3}u \text{ and } v_2 = \frac{4}{3}u$$

or the final velocity of A can be directly calculated by using the formula.

The velocity after collision is given by

$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \frac{2m_2u_2}{m_1 + m_2}$$

$$= \left(\frac{4m - 2m}{4m + 2m}\right)u + \frac{2(2m) \times 0}{(4m + 2m)} \quad [\because u_2 = u' = 0]$$

$$= \frac{2m}{6m}u = \frac{1}{3}u$$

$\therefore$ Net decreases in kinetic energy of A

$$\Delta\mathrm{KE} = \mathrm{KE}_A - \mathrm{KE}_A$$

$$= 2mu^2 - 2mv_1^2 = 2m(u^2 - v_1^2)$$

Substituting the value of v_1, we get

$$\Delta\mathrm{KE} = 2m\left(u^2 - \frac{u^2}{9}\right) = \frac{16mu^2}{9}$$

$\therefore$ The fractional decreases in kinetic energy is

$$\frac{\Delta\mathrm{KE}}{\mathrm{KE}_A} = \frac{16mu^2}{9} \times \frac{1}{2mu^2} = \frac{8}{9}$$

53 A moving block having mass m, collides with another stationary block having mass $4m$. The lighter block comes to rest after collision. When the initial velocity of the lighter block is v, then the value of coefficient of restitution (e) will be **[NEET 2018]**

(a) 0.8 (b) 0.25

(c) 0.5 (d) 0.4

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Ans. *(b)*

Since, the collision mentioned is an elastic head-on collision. Thus, according to the law of conservation of linear momentum, we get

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

where, m_1 and m_2 are the masses of the two blocks, respectively and u_1 and u_2 are their initial velocities and v_1 and v_2 are their final velocities, respectively.

Here, $m_1 = m, m_2 = 4m$

$u_1 = v, u_2 = 0$ and $v_1 = 0$

$$mv + 4m \times 0 = 0 + 4mv_2$$

$$\Rightarrow \quad mv = 4mv_2 \quad \text{or} \quad v_2 = \frac{v}{4} \qquad ...(i)$$

As, the coefficient of restitution is given as,

$$e = \frac{\text{relative velocity of separation after collision}}{\text{relative velocity of approach}}$$

$$= \frac{v_2 - v_1}{u_2 - u_1} = \frac{\frac{v}{4} - 0}{0 - v} \qquad \text{[from Eq. (i)]}$$

$$= \frac{1}{4}$$

$$\therefore \ e = 0.25$$

54 Two identical balls *A* and *B* having velocities of 0.5 m/s and $-0.3\ \mathbf{m/s}$ respectively collide elastically in one dimension. The velocities of *B* and *A* after the collision respectively will be **[NEET 2016]**

(a) −0.5 m/s and 0.3 m/s
(b) 0.5 m/s and −0.3 m/s
(c) −0.3 m/s and 0.5 m/s
(d) 0.3 m/s and 0.5 m/s

Ans. *(c)*

In elastic collision, kinetic energy of the system remains unchanged and momentum is also conserved.

It is given that mass of balls are same and collision is perfectly elastic ($e = 1$) so their velocities will be interchanged.

Thus, $v_A' = v_B = -0.3$ m/s,

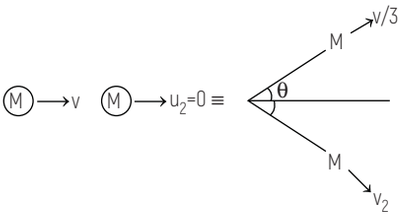
$v_B' = v_A = 0.5$ m/s

55 On a frictionless surface, a block of mass *M* moving at speed *v* collides elastically with another block of same mass *M* which is initially at rest. After collision the first block moves at an angle θ to its initial direction and has a speed *v*/3. The second block's speed after the collision is **[CBSE AIPMT 2015]**

(a) $\frac{2\sqrt{2}}{3}v$ (b) $\frac{3}{4}v$

(c) $\frac{3}{\sqrt{2}}v$ (d) $\frac{\sqrt{3}}{2}v$

Ans. *(a)*



According to law of conservation of kinetic energy, we have

$$\frac{1}{2}Mv^2 + 0 = \frac{1}{2}M\left(\frac{v}{3}\right)^2 + \frac{1}{2}Mv_2^2$$

$$\Rightarrow \quad v^2 = \frac{v^2}{9} + v_2^2$$

$$\Rightarrow \quad v^2 - \frac{v^2}{9} = v_2^2 \quad \Rightarrow \quad \frac{8v^2}{9}$$

Velocity of second block after collision

$$v_2 = \frac{2\sqrt{2}}{3}v$$

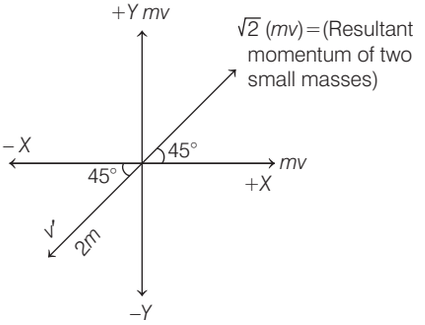
56 A body of mass (4*m*) is lying in *xy*-plane at rest. It suddenly explodes into three pieces. Two pieces each of mass (*m*) move perpendicular to each other with equal speeds (*v*). The total kinetic energy generated due to explosion is **[CBSE AIPMT 2014]**

(a) mv^2 (b) $\frac{3}{2}mv^2$

(c) $2mv^2$ (d) $4mv^2$

Ans. *(b)*

Problem Solving Strategy Conserve the momentum of third mass with the resultant momentum of 1st and 2nd masses. After getting velocity of third mass, calculate total kinetic energy.



According to question, the third part of mass 2*m* will move as shown in the figure, because the total momentum of the system after explosion must remain zero. Let the velocity of third part be v'.

From the conservation of momentum

$$\sqrt{2}(mv) = (2m) \times v'$$

$$\Rightarrow \quad v' = \frac{v}{\sqrt{2}}$$

So, total kinetic energy generated by the explosion

$$= \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + \frac{1}{2}(2m)v'^2$$

$$= mv^2 + m \times \left(\frac{v}{\sqrt{2}}\right)^2$$

$$= mv^2 + \frac{mv^2}{2}$$

$$= \frac{3}{2}mv^2$$

57 A ball moving with velocity $2\ \mathrm{ms^{-1}}$ collides head on with another stationary ball of double the mass. If the coefficient of restitution is 0.5, then their velocities $(\mathbf{in\ ms^{-1}})$ after collision will be **[CBSE AIPMT 2010]**

(a) 0,1 (b) 1, 1
(c) 1, 0.5 (d) 0, 2

Ans. *(a)*

If two bodies collide head on with coefficient of restitution

$$e = \frac{v_2 - v_1}{u_1 - u_2} \qquad ...(i)$$

From, the law of conservation of linear momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$\Rightarrow \quad v_1 = \left[\frac{m_1 - em_2}{m_1 + m_2}\right]u_1 + \left[\frac{(1+e)m_2}{m_1 + m_2}\right]u_2$$

Substituting $u_1 = 2\ \mathrm{ms^{-1}}$, $u_2 = 0$, $m_1 = m$ and $m_2 = 2m$, $e = 0.5$

we get, $v_1 = \left[\frac{m - m}{m + 2m}\right] \times 2$

$$\Rightarrow \quad v_1 = 0$$

Similarly,

$$v_2 = \left[\frac{(1+e)m_1}{m_1 + m_2}\right]u_1 + \left[\frac{m_2 - em_1}{m_1 + m_2}\right]u_2$$

$$= \left[\frac{1.5 \times m}{3m}\right] \times 2 = 1\ \mathrm{ms^{-1}}$$

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58 An explosion blows a rock into three parts. Two parts go off at right angles to each other. These two are, 1 kg first part moving with a velocity of 12 ms^{-1} and 2 kg second part moving with a velocity of 8 ms^{-1}. If the third part flies off with a velocity of 4 ms^{-1}, its mass would be **[CBSE AIPMT 2009]**

(a) 5 kg (b) 7 kg (c) 17 kg (d) 3 kg

Ans. *(a)*

Momentum of first part = $1 \times 12 = 12$ kg ms^{-1}

Momentum of the second part

$$= 2 \times 8 = 16 \text{ kg ms}^{-1}$$

$\therefore$ Resultant momentum

$$= \sqrt{(12)^2 + (16)^2} = 20 \text{ kg ms}^{-1}$$

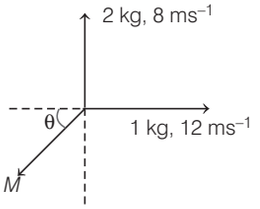
The third part should also have the same momentum.

Let the mass of the third part be M, then

$$4 \times M = 20$$

$$M = 5 \text{ kg}$$

Alternative



$$Mv\cos\theta = 12 \quad \text{...(i)}$$

$$Mv\sin\theta = 16 \quad \text{...(ii)}$$

Dividing Eqs. (ii) and (i), we get

$$\tan\theta = \frac{16}{12} = \frac{4}{3}$$

$$M = \frac{12 \times 5}{4 \times 3} = \frac{60}{12} = 5 \text{ kg}$$

59 A shell of mass 200 g is ejected from a gun of mass 4 kg by an explosion that generates 1.05 kJ of energy. The initial velocity of the shell is **[CBSE AIPMT 2008]**

(a) 100 ms^{-1} (b) 80 ms^{-1}
(c) 40 ms^{-1} (d) 120 ms^{-1}

Ans. *(a)*

Problem Solving Strategy Make two equations, one from conservation of momentum and other from convservation of energy and solve it.

Let the velocity of shell be v and that of gun be V. Then, according to conservation of linear momentum.

$$4V + 0.2v = 0 \quad \text{...(i)}$$

Using conservation of energy

$$\frac{1}{2} \times 4 \times V^2 + \frac{1}{2} \times 0.2 \times v^2 = 1050 \quad \text{...(ii)}$$

Solving Eqs. (i) and (ii), we get

$$v = 100 \text{ m/s}$$

60 A stationary particle explodes into two particles of masses m_1 and m_2, which move in opposite directions with velocities v_1 and v_2. The ratio of their kinetic energies E_1/E_2 is **[CBSE AIPMT 2003]**

(a) 1 (b) $\frac{m_1 v_2}{m_2 v_1}$

(c) $\frac{m_2}{m_1}$ (d) $\frac{m_1}{m_2}$

Ans. *(c)*

From conservation of linear momentum,

Initial momentum $p_{initial}$ = Find momentum p_{final}

$$0 = m_1 v_1 - m_2 v_2$$

or $$m_1 v_1 = m_2 v_2$$

or $$\frac{v_1}{v_2} = \frac{m_2}{m_1} \quad \text{...(i)}$$

Thus, ratio of kinetic energies,

$$\frac{K_1}{K_2} = \frac{\frac{1}{2} m_1 v_1^2}{\frac{1}{2} m_2 v_2^2} = \frac{m_1}{m_2} \times \left(\frac{m_2}{m_1}\right)^2 = \frac{m_2}{m_1}$$

61 Two equal masses m_1 and m_2 moving along the same straight line with velocities +3 m/s and −5 m/s respectively collide elastically. Their velocities after the collision will be respectively **[CBSE AIPMT 1998]**

(a) +4 m/s for both
(b) −3 m/s and +5 m/s
(c) −4 m/s and +4 m/s
(d) −5 m/s and +3 m/s

Ans. *(d)*

Given,

$u_1 = 3 \text{ m/s}, u_2 = -5 \text{ m/s}, m_1 = m_2 = m$ According to principle of conservation of linear momentum,

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$m \times 3 - m \times 5 = m v_1 + m v_2$$

or $$v_1 + v_2 = -2 \quad \text{...(i)}$$

In an elastic collision,

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

$\Rightarrow$ $$v_2 - v_1 = e(u_1 - u_2)$$

$\Rightarrow$ $$v_2 - v_1 = (1)(3 + 5) \quad (\because e = 1)$$

$\Rightarrow$ $$v_1 - v_2 = -8 \quad \text{...(ii)}$$

Adding Eqs. (i) and (ii), we obtain

$$2v_1 = -10$$

$\Rightarrow$ $$v_1 = -5 \text{ m/s}$$

From Eq. (i),

$$v_2 = -2 - v_1 = -2 + 5 = 3 \text{ m/s}$$

Thus, $v_1 = -5 \text{ m/s}, v_2 = +3 \text{ m/s}$

If two bodies collide elastically, then their velocities are interchanged. Since, it is an elastic collision hence, velocities after collision will be − 5 m/s and 3 m/s.

62 A metal ball of mass 2 kg moving with a velocity of 36 km/h has a head on collision with a stationary ball of mass 3 kg. If after the collision, the two balls move together, the loss in kinetic energy due to collision is **[CBSE AIPMT 1997]**

(a) 140 J (b) 100 J (c) 60 J (d) 40 J

Ans. *(c)*

Initial momentum = Final momentum

$\therefore$ $$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v$$

Given, $v_1 = 36 \text{ km/h}$

$$= 36 \times \frac{5}{18} = 10 \text{ m/s},$$

$$v_2 = 0$$

$$m_1 = 2 \text{ kg}, m_2 = 3 \text{ kg}$$

$\therefore$ $$v = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$

$$= \frac{2 \times 10 + 3 \times 0}{2 + 3}$$

or $$v = \frac{20}{5} = 4 \text{ m/s}$$

Loss in kinetic energy

$$= \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 - \frac{1}{2}(m_1 + m_2) v^2$$

$$= \frac{1}{2} \times 2 \times (10)^2 + 0 - \frac{1}{2}(2 + 3) \times (4)^2$$

$$= 100 - 40 = 60 \text{ J}$$

63 A metal ball of mass 2 kg moving with a velocity of 36 km/h has a head on collision with a stationary ball of mass 3 kg. If after the collision, the two balls move together, the loss in kinetic energy due to collision is **[CBSE AIPMT 1997]**

(a) 140 J (b) 100 J
(c) 60 J (d) 40 J

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Ans. *(c)*

Initial momentum = Final momentum

$\therefore \quad m_1 v_1 + m_2 v_2 = (m_1 + m_2)\, v$

Given, $v_1 = 36\,\text{km/h} = 36 \times \frac{5}{18} = 10\,\text{m/s}$,

$v_2 = 0$

$m_1 = 2\,\text{kg}, m_2 = 3\,\text{kg}$

$\therefore \quad v = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$

$= \frac{2 \times 10 + 3 \times 0}{2 + 3}$

or $\quad v = \frac{20}{5} = 4\,\text{m/s}$

Loss in kinetic energy

$= \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 - \frac{1}{2}(m_1 + m_2)\, v^2$

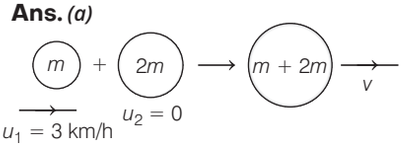
$= \frac{1}{2} \times 2 \times (10)^2 + 0 - \frac{1}{2}(2 + 3) \times (4)^2$

$= 100 - 40 = 60\,\text{J}$

64 A body of mass m moving with velocity 3 km / h collides with a body of mass 2 m at rest. Now, the coalesced mass starts to move with a velocity **[CBSE AIPMT 1996]**

(a) 1 km/h (b) 2 km/h
(c) 3 km/h (d) 4 km/h

Ans. *(a)*



Let v be velocity of combined mass after collision.

Applying law of conservation of linear momentum

Initial momentum = Final momentum

$m \times 3 + 2m \times 0 = (m + 2m)\, v$

or $\quad 3m = 3mv$ or $v = 1\,\text{km / h}$

65 Two identical balls A and B moving with velocities + 0.5 m/s and – 0.3 m/s respectively, collide head on elastically. The velocity of the balls A and B after collision will be respectively **[CBSE AIPMT 1991]**

(a) + 0.5 m/s and + 0.3 m/s
(b) – 0.3 m/s and + 0.5 m/s
(c) + 0.3 m/s and 0.5 m/s
(d) – 0.5 m/s and + 0.3 m/s

Ans. *(b)*

When two bodies of equal masses undergo head on elastic collision in one dimension their velocities are just interchanged.

66. The coefficient of restitution e for a perfectly elastic collision is **[CBSE AIPMT 1988]**

(a) 1 (b) zero
(c) infinite (d) –1

Ans. *(a)*

The degree of elasticity of a collision is determined by a quantity called coefficient of restitution or coefficient of resilience of the collision. It is defined as the ratio of relative velocity of separation after collision to the relative velocity of approach before collision. It is represented by e.

$$e = \frac{\text{relative velocity of separation (after collision)}}{\text{relative velocity of approach (before collision)}}$$

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

where, u_1, u_2 are the velocities of two bodies before collision and v_1, v_2 are their respective velocities after collision.

For a perfectly elastic collision, relative velocity of separation after collision is equal to relative velocity of approach before collision

$\therefore \quad e = 1$

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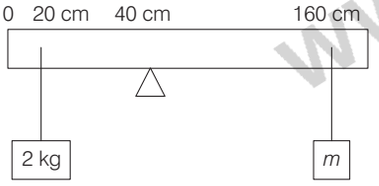
06

System of Particles and Rotational Motion

TOPIC 1
Centre of Mass, Torque and Angular Momentum

01 A uniform rod of length 200 cm and mass 500 g is balanced on a wedge placed at 40 cm mark. A mass of 2 kg is suspended from the rod at 20 cm and another unknown mass m is suspended from the rod at 160 cm mark as shown in the figure. Find the value of m such that the rod is in equilibrium. ($g = 10\ m/s^2$) **[NEET 2021]**



(a) $\frac{1}{2}$ kg (b) $\frac{1}{3}$ kg

(c) $\frac{1}{6}$ kg (d) $\frac{1}{12}$ kg

Ans. *(d)*

Given, the length of a uniform rod, $L = 200$ cm

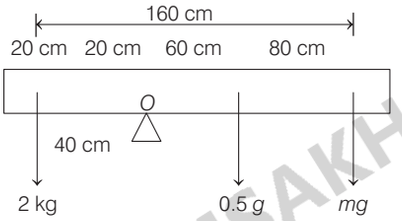
The wedge is placed at the mark = 40 cm

The balanced mass placed at 100 cm mark on wedge = 500 g = 0.5 kg

The mass suspended from the rod at 20 cm distance from the end, $M = 2$ kg

Another unknown mass suspended from the rod at 160 cm distance from the end = m

Let's draw the diagram of the uniform rod suspended with mass.



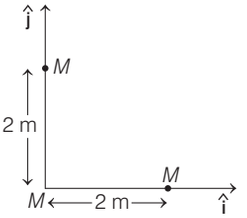
As we know in equilibrium net moment of force is equals to zero.

$\Rightarrow 0.5g\,(0.60) + mg\,(1.20) - 2g\,(0.20) = 0$

$\Rightarrow 0.3 + 1.20\,m - 0.4 = 0$

$\Rightarrow 1.20\,m = 0.1 \ \Rightarrow\ m = \frac{1}{12}$ kg

02 Three identical spheres, each of mass M, are placed at the corners of a right angle triangle with the mutually perpendicular sides equal to 2 m (see figure). Taking the point of intersection of the two mutually perpendicular sides as the origin, find the position vector of centre of mass. **[NEET (Oct.) 2020]**

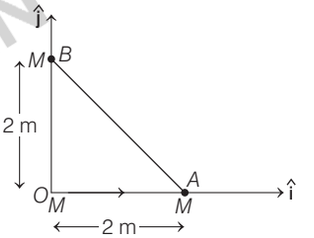


(a) $2(\hat{i} + \hat{j})$ (b) $(\hat{i} + \hat{j})$

(c) $\frac{2}{3}(\hat{i} + \hat{j})$ (d) $\frac{4}{3}(\hat{i} + \hat{j})$

Ans. *(b)*

The given situation is shown in the figure.



$\mathbf{OA} = 2\hat{\mathbf{i}}$

$\mathbf{OB} = 2\hat{\mathbf{j}}$

Position vector of centre of mass,

$$\boldsymbol{R}_{CM} = \frac{m_1\mathbf{r}_1 + m_2\mathbf{r}_2}{M_1 + M_2}$$

$$= \frac{M\mathbf{OA} + M\mathbf{OB}}{M + M}$$

$$= \frac{M \times 2\hat{\mathbf{i}} + M \times 2\hat{\mathbf{j}}}{2M} = \hat{\mathbf{i}} + \hat{\mathbf{j}}$$

03 Find the torque about the origin when a force of $3\hat{\mathbf{j}}$ N acts on the particle whose position vector is $2\hat{\mathbf{k}}$ m. **[NEET (Sep.) 2020]**

(a) $6\,\hat{\mathbf{j}}$ N-m (b) $-6\,\hat{i}$ N-m

(c) $6\,\hat{\mathbf{k}}$ N-m (d) $6\,\hat{\mathbf{i}}$ N-m

Ans. *(b)*

Given, position vector, $\mathbf{r} = 2\hat{\mathbf{k}}$ m

Force, $\mathbf{F} = 3\hat{\mathbf{j}}$ N

As, torque, $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F} = 2\hat{\mathbf{k}} \times 3\hat{\mathbf{j}} = 6(-\hat{\mathbf{i}})$

$= -6\hat{\mathbf{i}}$ N-m

Hence, correct option is (b).

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04 Two particles of mass 5 kg and 10 kg respectively are attached to the two ends of a rigid rod of length 1 m with negligible mass.

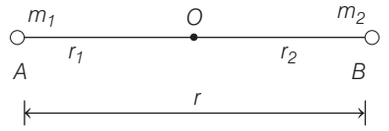
The centre of mass of the system from the 5 kg particle is nearly at a distance of **[NEET (Sep.) 2020]**

(a) 50 cm (b) 67 cm
(c) 80 cm (d) 33 cm

Ans. *(b)*

Given, $m_1 = 5\,kg$, $m_2 = 10\,kg$ and $r = 1\,m = 100\,cm$

Let the centre of mass lies at origin *O*.



$$\therefore \quad \frac{m_1 r_1 - m_2 r_2}{m_1 + m_2} = 0$$

$$\Rightarrow \quad 5r_1 - 10r_2 = 0$$

$$\Rightarrow \quad r_2 = \frac{r_1}{2}$$

Also, $r_1 + r_2 = 100$

$$\Rightarrow \quad r_1 + \frac{r_1}{2} = 100$$

$$\Rightarrow \quad 3r_1 = 200$$

$$\Rightarrow \quad r_1 = \frac{200}{3} \simeq 67\,cm$$

Hence, correct option is (b).

05 The moment of the force, $\mathbf{F} = 4\hat{\mathbf{i}} + 5\hat{\mathbf{j}} - 6\hat{\mathbf{k}}$ at (2, 0, –3), about the point (2, –2, –2), is given by **[NEET 2018]**

(a) $-7\hat{\mathbf{i}} - 8\hat{\mathbf{j}} - 4\hat{\mathbf{k}}$ (b) $-4\hat{\mathbf{i}} - \hat{\mathbf{j}} - 8\hat{\mathbf{k}}$
(c) $-8\hat{\mathbf{i}} - 4\hat{\mathbf{j}} - 7\hat{\mathbf{k}}$ (d) $-7\hat{\mathbf{i}} - 4\hat{\mathbf{j}} - 8\hat{\mathbf{k}}$

Ans. *(d)*

Key Concept *Moment of force is defined as the cross product of the force and the force arm.*

Given, $\mathbf{F} = 4\hat{\mathbf{j}} + 5\hat{\mathbf{j}} - 6\hat{\mathbf{k}}$

$\mathbf{r}_1 = 2\hat{\mathbf{i}} + 0\hat{\mathbf{j}} - 3\hat{\mathbf{k}}$

$\mathbf{r}_2 = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}} - 2\hat{\mathbf{k}}$

Moment of force $= \mathbf{r} \times \mathbf{F}$

$= (\mathbf{r}_1 - \mathbf{r}_2) \times \mathbf{F}$

$= [-(2\hat{\mathbf{i}} - 2\hat{\mathbf{j}} - 2\hat{\mathbf{k}}) + (2\hat{\mathbf{i}} + 0\hat{\mathbf{j}} - 3\hat{\mathbf{k}})] \times [4\hat{\mathbf{i}} + 5\hat{\mathbf{j}} - 6\hat{\mathbf{k}}]$

$= [0\,\hat{\mathbf{i}} + 2\hat{\mathbf{j}} - 1\hat{\mathbf{k}}] \times [4\hat{\mathbf{i}} + 5\hat{\mathbf{j}} - 6\hat{\mathbf{k}}]$

$$= \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 0 & 2 & -1 \\ 4 & 5 & -6 \end{vmatrix}$$

$= \hat{\mathbf{i}}[(-6 \times 2) - (-1 \times 5)]$

$- \hat{\mathbf{j}}[(-6 \times 0) - (-1 \times 4)] + \hat{\mathbf{k}}[(0 \times 5) - 2 \times 4]$

$= -7\hat{\mathbf{i}} - 4\hat{\mathbf{j}} - 8\hat{\mathbf{k}}$

06 A rope is wound around a hollow cylinder of mass 3 kg and radius 40 cm. What is the angular acceleration of the cylinder, if the rope is pulled with a force of 30 N? **[NEET 2017]**

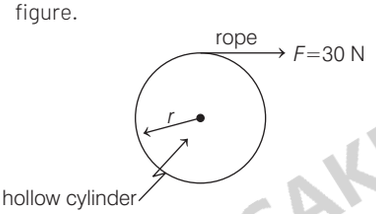
(a) 25 m/s^2 (b) 0.25 rad/s^2
(c) 25 rad/s^2 (d) 5 m/s^2

Ans. *(c)*

Thinking Process Torque (τ) acting on a body and angular acceleration (α) produced in it are related as

$$\tau = I\alpha$$

Consider a hollow cylinder, around which a rope is wounded as shown in the figure.



Torque acting on the cylinder due to the force *F* is

$$\tau = Fr$$

Now, we have $\tau = I\alpha$

where, I = moment of inertia of the cylinder about the axis through the centre $= mr^2$

α = angular acceleration

$$\Rightarrow \quad \alpha = \frac{\tau}{I} = \frac{Fr}{mr^2} = \frac{F}{mr} = \frac{30}{3 \times 40 \times 10^{-2}}$$

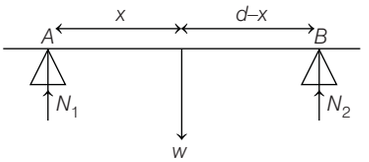
$$= \frac{100}{4} = 25\,rad/s^2$$

07 A rod of weight *w* is supported by two parallel knife edges *A* and *B* and is in equilibrium in a horizontal position. The knives are at a distance *d* from each other. The centre of mass of the rod is at distance *x* from *A*. The normal reaction on *A* is **[CBSE AIPMT 2015]**

(a) $\frac{wx}{d}$ (b) $\frac{wd}{x}$
(c) $\frac{w(d-x)}{x}$ (d) $\frac{w(d-x)}{d}$

Ans. *(d)*

As the weight w balances the normal reactions.



So, $w = N_1 + N_2$ ...(i)

Now balancing torque about the COM,

i.e. anti-clockwise momentum = clockwise momentum

$$\Rightarrow \quad N_1 x = N_2 (d - x)$$

Putting the value of N_2 from Eq. (i), we get

$$N_1 x = (w - N_1)(d - x)$$

$$\Rightarrow \quad N_1 x = wd - wx - N_1 d + N_1 x$$

$$\Rightarrow \quad N_1 d = w(d - x)$$

$$\Rightarrow \quad N_1 = \frac{w(d-x)}{d}$$

08 An automobile moves on a road with a speed of 54 kmh^{-1}. The radius of its wheels is 0.45 m and the moment of inertia of the wheel about its axis of rotation is 3 kg m^2. If the vehicle is brought to rest in 15 s, the magnitude of average torque transmitted by its brakes to the wheel is **[CBSE AIPMT 2015]**

(a) 6.66 kg m^2 s^{-2} (b) 8.58 kg m^2 s^{-2}
(c) 10.86 kg m^2 s^{-2} (d) 2.86 kg m^2 s^{-2}

Ans. *(a)*

As velocity of an automobile vehicle,

$$v = 54\,km/h = 54 \times \frac{5}{18} = 15\,m/s$$

Angular velocity of a vehicle, $v = \omega_0 r$

$$\Rightarrow \quad \omega_0 = \frac{v}{R} = \frac{15}{0.45} = \frac{100}{3}\,rad/s$$

So, angular acceleration of an automobile,

$$\alpha = \frac{\Delta\omega}{t} = \frac{\omega_f - \omega_0}{t} = \frac{0 - \frac{100}{3}}{15}$$

$$= \frac{-100}{45}\,rad/s^2$$

Thus, average torque transmitted by its brakes to wheel

$$\tau = I\alpha \quad \Rightarrow \quad 3 \times \frac{100}{45} = 6.66\,kgm^2 s^{-2}$$

09 A force $\mathbf{F} = \alpha\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + 6\hat{\mathbf{k}}$ is acting at a point $\mathbf{F} = 2\hat{\mathbf{i}} - 6\hat{\mathbf{j}} - 12\hat{\mathbf{k}}$. The value of α for which angular momentum about origin is conserved is **[CBSE AIPMT 2014]**

(a) – 1 (b) 2 (c) zero (d) 1

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Ans. *(a)*

Key Concept When the resultant external torque acting on a system is zero, the total angular momentum of a system remains constant. This is the principle of the conservation of angular momentum.

Given, force $\mathbf{F} = \alpha\,\hat{\mathbf{i}} + 3\,\hat{\mathbf{j}} + 6\,\hat{\mathbf{k}}$ is acting at a point

$$\mathbf{r} = 2\,\hat{\mathbf{i}} - 6\,\hat{\mathbf{j}} - 12\hat{\mathbf{k}}$$

As, angular momentum about origin is conserved.

i.e. $\tau = \text{constant}$

$\Rightarrow$ Torque, $\tau = 0 \Rightarrow \mathbf{r} \times \mathbf{F} = 0$

$$\begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 2 & -6 & -12 \\ \alpha & 3 & 6 \end{vmatrix} = 0$$

$\Rightarrow$

$$(-36 + 36)\hat{\mathbf{i}} - (12 + 12\alpha)\hat{\mathbf{j}} + (6 + 6\alpha)\hat{\mathbf{k}} = 0$$

$$\Rightarrow \quad 0\,\hat{\mathbf{i}} - 12(1 + \alpha)\hat{\mathbf{i}} + 6(1 + \alpha)\hat{\mathbf{k}} = 0$$

$$\Rightarrow \quad 6(1 + \alpha) = 0$$

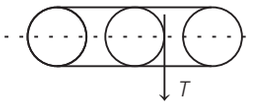
$$\Rightarrow \quad \alpha = -1$$

So, value of α for angular momentum about origin is conserved, $\alpha = -1$

10 A solid cylinder of mass 50 kg and radius 0.5 m is free to rotate about the horizontal axis. A massless string is wound round the cylinder with one end attached to it and other hanging freely. Tension in the string required to produce an angular acceleration of 2 rev/s^2 is **[CBSE AIPMT 2014]**

(a) 25 N (b) 50 N (c) 78.5 N (d) 157 N

Ans. *(d)*



Given, $m = 50$ kg, $r = 0.5$ m,

$\alpha = 2$ rev / s^2

$\Rightarrow$ Torque produced by the tension in the string

$$= T \times r = T \times 0.5 = \frac{T}{2}\ \text{N-m} \qquad \ldots(i)$$

We know $\tau = I\alpha$ ...(ii)

From Eqs. (i) and (ii), $\frac{T}{2} = I\alpha$

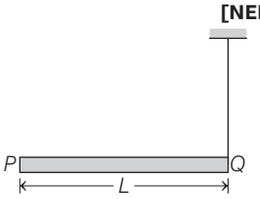
$$= \left(\frac{MR^2}{2}\right) \times (2 \times 2\pi)\ \text{rad / s}^2$$

$$\left[\text{because } I_{\text{Solid cylinder}} = \frac{MR^2}{2}\right]$$

$$\frac{T}{2} = \frac{50 \times (0.5)^2}{2} \times 4\pi$$

$$T = 50 \times \frac{1}{4} \times 4\pi = 50\ \pi = 157\ \text{N}$$

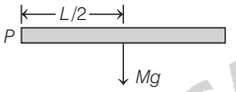
11 A rod PQ of mass M and length L is hinged at end P. The rod is kept horizontal by a massless string tied to a point Q as shown in figure. When string is cut, the initial angular acceleration of the rod is **[NEET 2013]**



(a) $\frac{3g}{2L}$ (b) $\frac{g}{L}$ (c) $\frac{2g}{L}$ (d) $\frac{2g}{3L}$

Ans. *(a)*

Concept Torque on the rod is equal to moment of weight of rod about P.



Torque on the rod = Moment of weight of the rod about P

$$\tau = Mg\frac{L}{2} \qquad \ldots(i)$$

$\because$ Moment of inertia of rod about $P = \frac{ML^2}{3}$ ...(ii)

As $\tau = I\alpha$

From Eqs. (i) and (ii), we get

$$Mg\frac{L}{2} = \frac{ML^2}{3}\alpha \ \Rightarrow\ \alpha = \frac{3g}{2L}$$

12 When a mass is rotating in a plane about a fixed point, its angular momentum is directed along **[CBSE AIPMT 2012]**

(a) a line perpendicular to the plane of rotation
(b) the line making an angle of 45° to the plane of rotation
(c) the radius
(d) the tangent to the orbit

Ans. *(a)*

As we know that

Angular momentum $\mathbf{L} = m(\mathbf{r} \times \mathbf{v})$

So, here angular momentum is directed along a line perpendicular to the plane of rotation.

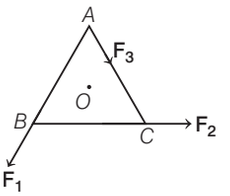
13 Two persons of masses 55 kg and 65 kg respectively, are at the opposite ends of a boat. The length of the boat is 3 m and weighs 100 kg. The 55 kg man walks upto the 65 kg man and sits with him. If the boat is in still water the centre of mass of the system shifts by **[CBSE AIPMT 2012]**

(a) 3 m (b) 2.3 m
(c) zero (d) 0.75 m

Ans. *(c)*

Here on the entire system net external force on the system is zero hence centre of mass remains unchanged.

14 ABC is an equilateral triangle with O as its centre. $\mathbf{F}_1$, $\mathbf{F}_2$ and $\mathbf{F}_3$ represent three forces acting along the sides AB, BC and AC, respectively. If the total torque about O is zero, then the magnitude of $\mathbf{F}_3$ is **[CBSE AIPMT 2012]**



(a) $F_1 + F_2$ (b) $F_1 - F_2$
(c) $\frac{F_1 + F_2}{2}$ (d) $2(F_1 + F_2)$

Ans. *(a)*

If we take clockwise torque

$$\tau_{\text{net}} = \tau_{F_1} + \tau_{F_2} + \tau_{F_3}$$

$$0 = F_1 r + F_2 r + F_3 r$$

$$\Rightarrow \quad F_3 = F_1 + F_2$$

15 The instantaneous angular position of a point on a rotating wheel is given by the equation $\theta(t) = 2t^3 - 6t^2$. The torque on the wheel becomes zero at **[CBSE AIPMT 2011]**

(a) $t = 0.5$ s (b) $t = 0.25$ s
(c) $t = 2$ s (d) $t = 1$ s

Ans. *(d)*

According to question, torque $\tau = 0$

It means that, $\alpha = 0$

$$\alpha = \frac{d^2\theta}{dt^2}$$

Given, $\theta(t) = 2t^3 - 6t^2$

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So, $\frac{d\theta}{dt} = 6t^2 - 12t$

$$\alpha = \frac{d^2\theta}{dt^2} = 12t - 12$$

$12t - 12 = 0 \Rightarrow t = 1\,s$

16 Two particles which are initially at rest, move towards each other under the action of their internal attraction. If their speeds are v and $2v$ at any instant, then the speed of centre of mass of the system will be **[CBSE AIPMT 2010]**

(a) $2v$ (b) 0
(c) $1.5v$ (d) v

Ans. *(b)*

As initially both the particles were at rest therefore velocity of centre of mass was zero and there is no external force on the system so speed of centre of mass remains constant i.e it should be equal to zero.

17 Two bodies of masres 1 kg and 3 kg have position vectors $\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + \hat{\mathbf{k}}$ and $-3\hat{\mathbf{i}} - 2\hat{\mathbf{j}} + \hat{\mathbf{k}}$, respectively. The centre of mass of this system has a position vector **[CBSE AIPMT 2009]**

(a) $-2\hat{\mathbf{i}} + 2\hat{\mathbf{k}}$ (b) $-2\hat{\mathbf{i}} - \hat{\mathbf{j}} + \hat{\mathbf{k}}$
(c) $2\hat{\mathbf{i}} - \hat{\mathbf{j}} - 2\hat{\mathbf{k}}$ (d) $-\hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}}$

Ans. *(b)*

The position vector of centre of mass

$$\mathbf{r} = \frac{m_1\mathbf{r}_1 + m_2\mathbf{r}_2}{m_1 + m_2}$$

$$= \frac{1(\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + \hat{\mathbf{k}}) + 3(-3\hat{\mathbf{i}} - 2\hat{\mathbf{j}} + \hat{\mathbf{k}})}{1+3}$$

$$= \frac{1}{4}(-8\hat{\mathbf{i}} - 4\hat{\mathbf{j}} + 4\hat{\mathbf{k}}) = -2\hat{\mathbf{i}} - \hat{\mathbf{j}} + \hat{\mathbf{k}}$$

18 A thin circular ring of mass M and radius R is rotating in a horizontal plane about an axis vertical to its plane with a constant angular velocity ω. If two objects each of mass m be attached gently to the opposite ends of a diameter of the ring, the ring will then rotate with an angular velocity **[CBSE AIPMT 2009, 1998]**

(a) $\frac{\omega(M-2m)}{M+2m}$ (b) $\frac{\omega M}{M+2m}$
(c) $\frac{\omega(M+2m)}{M}$ (d) $\frac{\omega M}{M+m}$

Ans. *(b)*

Concept Apply parallel axes theorem of moment of inertia.

According to question by applying conservation of angular momentum

$$I_1\omega_1 = I_2\omega_2$$

In the given case

$$I_1 = MR^2$$
$$I_2 = MR^2 + 2mR^2$$
$$\omega_1 = \omega$$

Then, $\omega_2 = \frac{I_1}{I_2}\omega = \frac{M}{M+2m}\omega$

19 If $\mathbf{F}$ is the force acting on a particle having position vector $\mathbf{r}$ and τ be the torque of this force about the origin, then **[CBSE AIPMT 2009]**

(a) $\mathbf{r}\cdot\tau \neq 0$ and $\mathbf{F}\cdot\tau = 0$
(b) $\mathbf{r}\cdot\tau > 0$ and $\mathbf{F}\cdot\tau < 0$
(c) $\mathbf{r}\cdot\tau = 0$ and $\mathbf{F}\cdot\tau = 0$
(d) $\mathbf{r}\cdot\tau = 0$ and $\mathbf{F}\cdot\tau \neq 0$

Ans. *(c)*

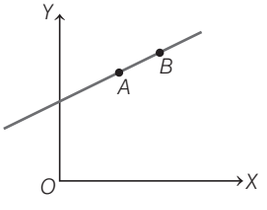
$\tau = \mathbf{r} \times \mathbf{F}$, where $\mathbf{r}$ = position vector

$\mathbf{F}$ = force $\Rightarrow \tau = |\mathbf{r}|\cdot|\mathbf{F}|\sin\theta$

Torque is perpendicular to both $\mathbf{r}$ and $\mathbf{F}$. So, dot product of two vectors will be zero.

$$\tau\cdot\mathbf{r} = 0 \Rightarrow \mathbf{F}\cdot\tau = 0$$

20 A particle of mass m in the XY-plane with a velocity v along the straight line AB. If the angular momentum of the particle with respect to origin O is L_A when it is at A and L_B when it is at B, then **[CBSE AIPMT 2007]**



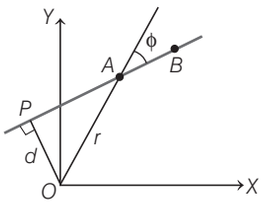
(a) $L_A > L_B$
(b) $L_A = L_B$
(c) the relationship between L_A and L_B depends upon the slope of the line AB
(d) $L_A < L_B$

Ans. *(b)*

From the definition of angular momentum,

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = rmv\sin\phi(-\mathrm{k})$$

[$\mathbf{r}$ = position vector, $\mathbf{p}$ = momentum]

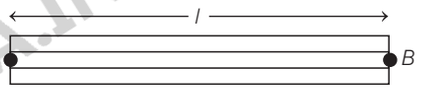


Therefore, the magnitude of L is

$$L = mvr\sin\phi = mvd$$

where, $d = r\sin\phi$ is the distance of closest approach of the particle to the origin. As d is same for both the particles, hence $L_A = L_B$.

21 A uniform rod of length l and mass m is free to rotate in a vertical plane about A. The rod initially in horizontal position is released. The initial angular acceleration of the rod is (moment of inertia of rod about A is $\frac{ml^2}{3}$) **[CBSE AIPMT 2007]**



(a) $\frac{3g}{2l}$ (b) $\frac{2l}{3g}$ (c) $\frac{3g}{2l^2}$ (d) $mg\frac{l}{2}$

Ans. *(a)*

The moment of inertia of the uniform rod about an axis through one end and perpendicular to length is

$$I = \frac{ml^2}{3}$$

where, m is mass of rod and l its length.

Torque ($\tau = I\alpha$) acting on centre of gravity of rod is given by

$$\tau = mg\frac{l}{2}$$

As we know that $\tau = I\alpha$

So $I\alpha = mg\frac{l}{2}$ or $\frac{ml^2}{3}\alpha = mg\frac{l}{2}$

$\therefore \quad \alpha = \frac{3g}{2l}$

22 A tube of length L is filled completely with an incompressible liquid of mass M and closed at both the ends. The tube is then rotated in a horizontal plane about one of its ends with a uniform angular velocity ω. The force exerted by the liquid at the other end is **[CBSE AIPMT 2006]**

(a) $\frac{ML\omega^2}{2}$ (b) $\frac{ML^2\omega}{2}$ (c) $ML\omega^2$ (d) $\frac{ML^2\omega^2}{2}$

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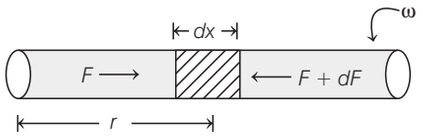
Ans. *(a)*

Let the length of a small element of tube be dx.

Mass of this element

$$dm = \frac{M}{L}dx$$



where, M is mass of filled liquid and L is length of tube. Force on this element

$$dF = dm \times x\omega^2$$

$$\int_0^F dF = \frac{M}{L}\omega^2 \int_0^L x\,dx$$

or $$F = \frac{M}{L}\omega^2\left[\frac{L^2}{2}\right] = \frac{ML\omega^2}{2}$$

or $$F = \frac{1}{2}ML\omega^2$$

23 Consider a system of two particles having masses m_1 and m_2. If the particle of mass m_1 is pushed towards the centre of mass of particles through a distance d, by what distance would the particle of mass m_2 move so as to keep the mass centre of particles at the original position?

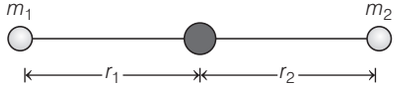
[CBSE AIPMT 2004]

(a) $\frac{m_1}{m_1+m_2}d$ (b) $\frac{m_1}{m_2}d$

(c) d (d) $\frac{m_2}{m_1}d$

Ans. *(b)*

The system of two given particles of masses m_1 and m_2 are shown in figure.



Initially the centre of mass

$$r_{CM} = \frac{m_1r_1 + m_2r_2}{m_1 + m_2} \quad ...(i)$$

When mass m_1 moves towards centre of mass by a distance d, then let mass m_2 moves a distance d' away from CM to keep the CM in its initial position.

So, $$r_{CM} = \frac{m_1(r_1 - d) + m_2(r_2 + d')}{m_1 + m_2} \quad ...(ii)$$

Equating Eqs. (i) and (ii), we get

$$\frac{m_1r_1 + m_2r_2}{m_1 + m_2} = \frac{m_1(r_1 - d) + m_2(r_2 + d')}{m_1 + m_2}$$

$$\Rightarrow \quad -m_1d + m_2d' = 0$$

$$\Rightarrow \quad d' = \frac{m_1}{m_2}d.$$

If both the masses are equal i.e., $m_1 = m_2$, then second mass will move a distance equal to the distance at which first mass is being displaced.

24 A round disc of moment of inertia I_2 about its axis perpendicular to its plane and passing through its centre is placed over another disc of moment of inertia I_1 rotating with an angular velocity ω about the same axis. The final angular velocity of the combination of discs is **[CBSE AIPMT 2004]**

(a) $\frac{I_2\omega}{I_1+I_2}$ (b) ω

(c) $\frac{I_1\omega}{I_1+I_2}$ (d) $\frac{(I_1+I_2)\omega}{I_1}$

Ans. *(c)*

Concept Apply conservation of angular momentum

The angular momentum of a disc of moment of inertia I_1 and rotating about its axis with angular velocity ω is

$$L_1 = I_1\omega$$

When a round disc of moment of inertia I_2 is placed on first disc, then angular momentum of the combination is

$$L_2 = (I_1 + I_2)\omega'$$

In the absence of any external torque, angular momentum remains conserved i.e.,

$$L_1 = L_2$$

$$I_1\omega = (I_1 + I_2)\omega'$$

$$\Rightarrow \quad \omega' = \frac{I_1\omega}{I_1 + I_2}$$

25 A thin circular ring of mass M and radius r is rotating about its axis with a constant angular velocity ω. Four objects each of mass m, are kept gently to the opposite ends of two perpendicular diameters of the ring. The angular velocity of the ring will be **[CBSE AIPMT 2003]**

(a) $\frac{(M+4m)\omega}{M}$ (b) $\frac{(M-4m)\omega}{M+4m}$

(c) $\frac{M\omega}{4m}$ (d) $\frac{M\omega}{M+4m}$

Ans. *(d)*

External torque $\tau_{ext} = 0$

So, $$\frac{dL}{dt} = 0$$

Angular momentum, L = constant

or $$I\omega = \text{constant}$$

$$\therefore \quad I_1\omega_1 = I_2\omega_2 \quad ...(i)$$

So, for two different cases

Here, $I_1 = Mr^2, \omega_1$

$= \omega, I_2 = Mr^2 + 4mr^2$

Hence, Eq. (i) can be written as

$$Mr^2\omega = (Mr^2 + 4mr^2)\omega_2$$

$$\therefore \quad \omega_2 = \frac{M\omega}{M+4m}$$

26 A rod is of length 3 m and its mass acting per unit length is directly proportional to distance x from its one end. The centre of gravity of the rod from that end will be at **[CBSE AIPMT 2002]**

(a) 1.5 m (b) 2 m (c) 2.5 m (d) 3 m

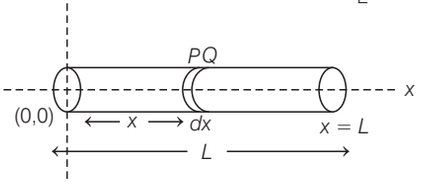
Ans. *(a)*

A rod lying along any of coordinate axes serves for us as continuous body.

Suppose a rod of mass M and length L is lying along the x-axis with its one end at $x = 0$ and the other at $x = L$.

Mass per unit length of the rod $= \frac{M}{L}$

Hence, the mass of the element PQ of length dx situated at $x = x$ is $dm = \frac{M}{L}dx$



The coordinates of the element PQ are $(x, 0, 0)$. Therefore, x-coordinate of centre of gravity of the rod will be

$$x_{CG} = \frac{\int_0^L x\,dm}{\int dm} = \frac{\int_0^L (x)\left(\frac{M}{L}\right)dx}{M} = \frac{1}{L}\int_0^L x\,dx$$

$$= \frac{L}{2}$$

but as given, $L = 3$ m

$$\therefore \quad x_{CG} = \frac{3}{2} = 1.5 \text{ m}$$

The y-coordinate of centre of gravity

$$y_{CG} = \frac{\int y\,dm}{\int dm} = 0 \qquad (\text{as } y = 0)$$

Similarly, $z_{CG} = 0$

i.e., the coordinates of centre of gravity of the rod are (1.5, 0, 0) or it lies at the distance 1.5 m from one end.

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27 A solid sphere of radius R is placed on a smooth horizontal surface. A horizontal force F is applied at height h from the lowest point. For the maximum acceleration of the centre of mass **[CBSE AIPMT 2002]**

(a) $h = R$
(b) $h = 2R$
(c) $h = 0$
(d) the acceleration will be same whatever h may be

Ans. *(d)*

The linear acceleration of centre of mass will be $a = \frac{F}{m}$, wherever the force is applied. Hence, the acceleration will be same whatever the value of h may be.

28 A disc is rotating with angular velocity ω. If a child sits on it, what is conserved ? **[CBSE AIPMT 2002]**

(a) Linear momentum
(b) Angular momentum
(c) Kinetic energy
(d) Moment of inertia

Ans. *(b)*

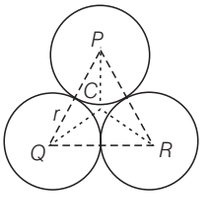
If no external torque is applied on the system, then angular momentum of the system remains constant. When a child sits on rotating disc, then no torque is applied (weight of child acts downward), so angular momentum will remain conserved.

29 Three identical metal balls each of radius r are placed touching each other on a horizontal surface such that an equilateral triangle is formed with centres of three balls joined. The centre of mass of the system is located at **[CBSE AIPMT 1999]**

(a) horizontal surface
(b) centre of one of the balls
(c) line joining the centres of any two balls
(d) point of intersection of the medians

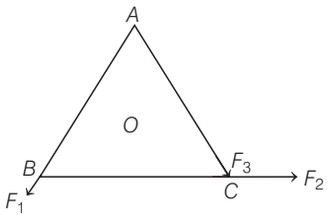
Ans. *(d)*

The whole mass of the ball will be concentrated at the centre of the ball. All the three balls are identical, i.e., the balls have same mass. On each vertex of equilateral ΔPQR, same mass is kept.



Therefore, centre of mass of the triangle is the centre of mass of the system which is point of intersection of the medians of the triangle.

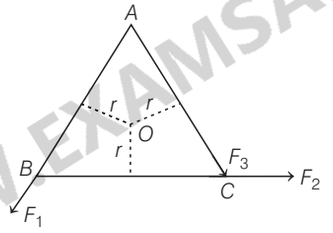
30 O is the centre of an equilateral ΔABC. F_1, F_2 and F_3 are three forces acting along the sides AB, BC and AC as shown in figure. What should be the magnitude of F_3, so that the total torque about O is zero? **[CBSE AIPMT 1998]**



(a) $\frac{(F_1 + F_2)}{2}$ (b) $(F_1 - F_2)$
(c) $(F_1 + F_2)$ (d) $2(F_1 + F_2)$

Ans. *(c)*

Let r be the perpendicular distance of F_1, F_2 and F_3 from O as shown in figure.



The torque of force F_3 about O is clockwise, while torque due to F_1 and F_2 are anticlockwise.

For total torque to be zero about O, we must have

$$F_1 r + F_2 r - F_3 r = 0$$

$$\Rightarrow \quad F_3 = F_1 + F_2$$

31 A couple produces **[CBSE AIPMT 1997]**

(a) no motion
(b) linear and rotational motion
(c) purely rotational motion
(d) purely linear motion

Ans. *(c)*

A couple consists of two equal and opposite forces acting at a separation, so that net force becomes zero. When a couple acts on a body it rotates the body but does not produce any translatory motion. Hence, only rotational motion is produced.

32 A cart of mass M is tied to one end of a massless rope of length 10 m. The other end of the rope is in the hands of a man of mass M. The entire system is on a smooth horizontal surface. The man is at $x = 0$ and the cart at $x = 10$ m. If the man pulls the cart by the rope, the man and the cart will meet at the point **[CBSE AIPMT 1997]**

(a) they will never meet
(b) $x = 10$ m
(c) $x = 5$ m
(d) $x = 0$

Ans. *(c)*

If the man pulls the cart by the rope, the man and cart will meet at the centre of mass.

$$\therefore \qquad x_{CM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

Taking axis at the point where man is present

$$= \frac{M \times 0 + M \times 10}{M + M} \qquad \begin{bmatrix} x_1 = 0, x_2 = 10 \\ m_1 = m_2 = M \end{bmatrix}$$

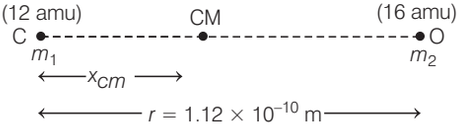
$$= \frac{10M}{2M} = 5 \text{ m}$$

33 In a carbon monoxide molecule, the carbon and the oxygen atoms are separated by a distance 1.12×10^{-10} m. The distance of the centre of mass from the carbon atom is **[CBSE AIPMT 1997]**

(a) 0.64×10^{-10} m (b) 0.56×10^{-10} m
(c) 0.51×10^{-10} m (d) 0.48×10^{-10} m

Ans. *(a)*

Let the distance of the centre of mass from the carbon atom be x_{cm}.
The mass of carbon, $m_1 = 12$ amu
The mass of oxygen, $m_2 = 16$ amu
[atomic mass unit]



From definition of centre of mass

$$x_{CM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

$$= \frac{(12 \text{ amu}) \times 0 + (16 \text{ amu}) \times r}{12 \text{ amu} + 16 \text{ amu}}$$

$$= \frac{16}{28} r = \frac{16}{28} \times 1.12 \times 10^{-10} \text{ m}$$

$$= 0.64 \times 10^{-10} \text{ m}$$

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34 Find the torque of *a* force $\mathbf{F} = -3\hat{\mathbf{i}} + \hat{\mathbf{j}} + 5\hat{\mathbf{k}}$ acting at the point $\mathbf{r} = 7\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + \hat{\mathbf{k}}$. **[CBSE AIPMT 1997]**

(a) $-21\hat{\mathrm{i}} + 3\hat{\mathrm{j}} + 5\hat{\mathrm{k}}$ (b) $-14\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 16\hat{\mathbf{k}}$

(c) $4\hat{\mathrm{i}} + 4\hat{\mathrm{j}} + 6\hat{\mathrm{k}}$ (d) $14\hat{\mathbf{i}} - 38\hat{\mathbf{j}} + 16\hat{\mathbf{k}}$

Ans. *(d)*

Given, $\mathbf{r} = 7\hat{\mathrm{i}} + 3\hat{\mathrm{j}} + \hat{\mathrm{k}}, \mathbf{F} = -3\hat{\mathbf{i}} + \hat{\mathbf{j}} + 5\hat{\mathbf{k}}$

$\therefore \quad \tau = \mathbf{r} \times \mathbf{F} = |\mathbf{r}||\mathbf{F}| \sin\theta$

where, θ is the angle between $\mathbf{r}$ and $\mathbf{F}$

$= (7\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (-3\hat{\mathbf{i}} + \hat{\mathbf{j}} + 5\hat{\mathbf{k}})$

$$= \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 7 & 3 & 1 \\ -3 & 1 & 5 \end{vmatrix}$$

$= \hat{\mathbf{i}}(15 - 1) - \hat{\mathbf{j}}(35 + 3) + \hat{\mathbf{k}}(7 + 9)$

$= 14\hat{\mathbf{i}} - 38\hat{\mathbf{j}} + 16\hat{\mathbf{k}}$

Alternative

$\therefore \quad \tau = \mathbf{r} \times \mathbf{F}$

$= (7\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + \hat{\mathbf{k}}) \times (-3\hat{\mathbf{i}} + \hat{\mathbf{j}} + 5\hat{\mathbf{k}})$

$= -21(\hat{\mathbf{i}} \times \hat{\mathbf{i}}) + 7(\hat{\mathbf{i}} \times \hat{\mathbf{j}}) + 35(\hat{\mathbf{i}} \times \hat{\mathbf{k}}) - 9(\hat{\mathbf{j}} \times \hat{\mathbf{i}}) + 3(\hat{\mathbf{j}} \times \hat{\mathbf{j}}) + 15(\hat{\mathbf{j}} \times \hat{\mathbf{k}}) - 3(\hat{\mathbf{k}} \times \hat{\mathbf{i}}) + (\hat{\mathbf{k}} \times \hat{\mathbf{j}}) + 5(\hat{\mathbf{k}} \times \hat{\mathbf{k}})$

$= 0 + 7\hat{\mathbf{k}} - 35\hat{\mathbf{j}} + 9\hat{\mathbf{k}} + 0 + 15\hat{\mathbf{i}} - 3\hat{\mathbf{j}} - \hat{\mathbf{i}} + 0$

$= 14\hat{\mathbf{i}} - 38\hat{\mathbf{j}} + 16\hat{\mathbf{k}}$

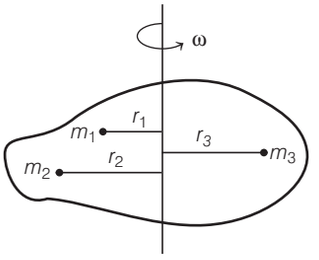
35 The angular momentum of a body with mass (m) moment of inertia (I) and angular velocity (ω) rad/s is equal to **[CBSE AIPMT 1996]**

(a) $I\omega$ (b) $I\omega^2$

(c) $\frac{I}{\omega}$ (d) $\frac{I}{\omega^2}$

Ans. *(a)*

Consider a rigid body rotating about a given axis with a uniform angular velocity ω. Let the body consists of n particles of masses $m_1, m_2, m_3, \ldots m_n$ at perpendicular distances $r_1, r_2, r_3, \ldots r_n$ respectively from the axis of rotation.



As the body is rigid, angular velocity ω of all the particles is the same. However, as the distances of the particles from the axis of rotation are different, their linear velocities are different. If $v_1, v_2, v_3, \ldots v_n$ are the linear velocities of the particles respectively, then

$$v_1 = r_1\omega$$
$$v_2 = r_2\omega$$
$$v_3 = r_3\omega, \ldots$$

The linear momentum of this particle of mass m_1 is

$$p_1 = m_1 v_1 = m_1 (r_1\omega)$$

The angular momentum of this particle about the given axis

$$= p_1 \times r_1 = (m_1 r_1\omega) \times r_1$$
$$= m_1 r_1^2 \omega$$

Similarly, angular momenta of other particles of the body about the given axis are

$$m_2 r_2^2\omega, m_3 r_3^2\omega, \ldots m_n r_n^2\omega$$

$\therefore$ Angular momentum of the body about the given axis

$$L = m_1 r_1^2\omega + m_2 r_2^2\omega + m_2 r_3^2\omega + \ldots + m_n r_n^2\omega$$
$$= (m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \ldots + m_n r_n^2)\omega$$

or $$L = \left(\sum_{i=1}^{n} m_i r_i^2\right)\omega$$

or $$L = I\omega$$

where, $I = \sum_{i=1}^{n} m_i r_i^2$ is moment of inertia of the body about the given axis.

36 Angular momentum is **[CBSE AIPMT 1994]**

(a) vector (axial)

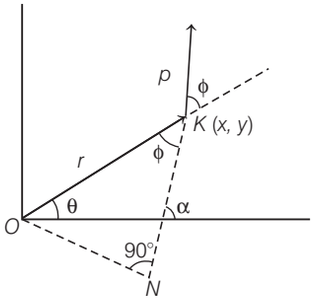
(b) vector (polar)

(c) scalar

(d) None of these

Ans. *(a)*

The radial component of linear momentum does not contribute to angular momentum of the particle. It is only the transverse component of linear momentum (perpendicular to position vector $\mathbf{r}$), which when multiplied by distance from the axis of rotation gives us angular momentum.



Hence, angular momentum is axial vector.

37 A particle of mass $m = 5\,\mathrm{kg}$ is moving with a uniform speed $v = 3\sqrt{2}$ in the XOY plane along the line $Y = X + 4$. The magnitude of the angular momentum of the particle about the origin is **[CBSE AIPMT 1991]**

(a) 60 unit

(b) $40\sqrt{2}$ unit

(c) zero

(d) 7.5 unit

Ans. *(a)*

The equation of the line is

$$Y = X + 4$$

or $$X - Y + 4 = 0$$

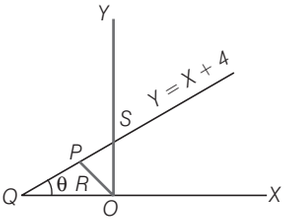
Length of perpendicular from origin on this line is

$$R = \frac{0 - 0 + 4}{\sqrt{1^2 + 1^2}} = \frac{4}{\sqrt{2}}$$

$\therefore$ Angular momentum

$$L = mvR = 5 \times 3\sqrt{2} \times \frac{4}{\sqrt{2}} = 60 \text{ unit}$$

Alternative



$Y = X + 4$ line is shown in the figure.

When $X = 0, \quad Y = 4,$

so $OS = 4$

To find slope of this line comparing this with equation of line

$$y = m'x + c$$

$\therefore$ Slope, $m' = \tan\theta = 1$

$\Rightarrow \quad \theta = 45°$

Length of perpendicular = OP

In ΔPSO, $\frac{OP}{OS} = \sin 45°$

$\therefore \quad OP = OS \sin 45°$

$$= 4 \times \frac{1}{\sqrt{2}} = \frac{4}{\sqrt{2}}$$

$\therefore$ Angular momentum of particle going along this line

$$= mvR$$
$$= 5 \times 3\sqrt{2} \times \frac{4}{\sqrt{2}}$$
$$= 60 \text{ unit}$$

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TOPIC 2
Moment of Inertia

38 From a circular ring of mass M and radius R, an arc corresponding to a 90° sector is removed. The moment of inertia of the remaining part of the ring about an axis passing through the centre of the ring and perpendicular to the plane of the ring is K times MR^2. Then, the value of K is **[NEET 2021]**

(a) $\frac{3}{4}$ (b) $\frac{7}{8}$ (c) $\frac{1}{4}$ (d) $\frac{1}{8}$

Ans. *(a)*

Given, the mass of the circular ring $= M$

The radius of the circular ring $= R$

We know that, the moment of inertia of the circular ring, $I = MR^2$

An arc corresponding to a 90° sector in the circular ring is removed, means one-fourth part of circular ring is removed. Then, the remaining mass of the circular ring,

$$M' = \frac{M}{4}$$

The new moment of inertia,

$$I' = M'R^2 = \frac{MR^2}{4}$$

Now, the moment of inertia of the remaining part,

$$I'' = I - I' = MR^2 - \frac{MR^2}{4} \Rightarrow I'' = \frac{3MR^2}{4}$$

Comparing with $I'' = KMR^2$

The value of $K = 3/4$.

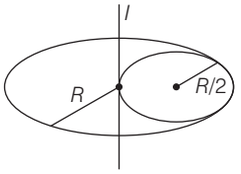
39 From a disc of radius R and mass M, a circular hole of diameter R, whose rim passes through the centre is cut. What is the moment of inertia of the remaining part of the disc about a perpendicular axis, passing through the centre ? **[NEET 2016]**

(a) $13MR^2/32$ (b) $11MR^2/32$

(c) $9MR^2/32$ (d) $15MR^2/32$

Ans. *(a)*

Considering the information given in the question, let us draw the figure



If the above figure is considered, then moment of inertia of disc will be given as

$$I = I_{\text{remain}} + I_{(R/2)} \Rightarrow I_{\text{remain}} = I - I_{(R/2)}$$

Putting the values, we get

$$= \frac{MR^2}{2} - \left[\frac{\frac{M}{4}\left(\frac{R}{2}\right)^2}{2} + \frac{M}{4}\left(\frac{R}{2}\right)^2\right]$$

$$= \frac{MR^2}{2} - \left[\frac{MR^2}{32} + \frac{MR^2}{16}\right]$$

$$= \frac{MR^2}{2} - \left[\frac{MR^2 + 2MR^2}{32}\right]$$

$$= \frac{MR^2}{2} - \frac{3MR^2}{32}$$

$$= \frac{16MR^2 - 3MR^2}{32}$$

$$I_{\text{remain}} = \frac{13MR^2}{32}$$

40 A light rod of length l has two masses m_1 and m_2 attached to its two ends. The moment of inertia of the system about an axis perpendicular to the rod and passing through the centre of mass is **[NEET 2016]**

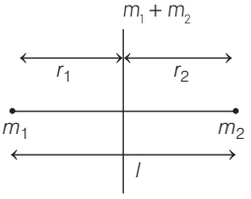
(a) $\frac{m_1m_2}{m_1+m_2}l^2$ (b) $\frac{m_1+m_2}{m_1m_2}l^2$

(c) $(m_1+m_2)l^2$ (d) $\sqrt{m_1m_2}l^2$

Ans. *(a)*

COM of m_1 and m_2 masses lies at

$$r = \frac{m_1r_1 + m_2r_2}{m_1+m_2}$$



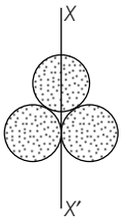
∴ Moment of inertia of the point masses about the given axis is

$$I = \sum m_i r_i^2 \Rightarrow I = m_1r_1^2 + m_2r_2^2$$

$$= m_1\left(\frac{m_2 l}{m_1+m_2}\right)^2 + m_2\left(\frac{m_1 l}{m_1+m_2}\right)^2$$

$$= \frac{m_1m_2l^2}{(m_1+m_2)^2}(m_2+m_1) = \frac{m_1m_2l^2}{(m_1+m_2)}$$

41 Three identical spherical shells, each of mass m and radius r are placed as shown in figure. Consider an axis XX', which is touching to two shells and passing through diameter of third shell.



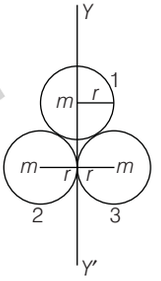
Moment of inertia of the system consisting of these three spherical shells about XX' axis is **[CBSE AIPMT 2015]**

(a) $\frac{11}{5}mr^2$ (b) $3mr^2$

(c) $\frac{16}{5}mr^2$ (d) $4mr^2$

Ans. *(d)*

The total moment of inertia of the system is



$$I = I_1 + I_2 + I_3 \quad \text{...(i)}$$

Here, $I_1 = \frac{2}{3}mr^2$

$$I_2 = I_3 = \frac{2}{3}mr^2 + mr^2$$

[From parallel axis theorem]

$$= \frac{5}{3}mr^2$$

From Eq. (i), $I = \frac{2}{3}mr^2 + 2\times\frac{5}{3}mr^2$

$$= mr^2\left(\frac{2}{3} + \frac{10}{3}\right)$$

$$I = 4mr^2$$

42 The moment of inertia of a thin uniform rod of mass M and length L about an axis passing through its mid-point and perpendicular to its length is I_0. Its moment of inertia about an axis passing through one of its ends and perpendicular to its length is **[CBSE AIPMT 2011]**

(a) $I_0 + ML^2/4$ (b) $I_0 + 2ML^2$

(c) $I_0 + ML^2$ (d) $I_0 + ML^2/2$

Ans. *(a)*

Concept Apply parallel axes theorem of moment of inertia.

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According to parallel axes theorem of moment of inertia,

$$I = I_{CM} + Mh^2$$

So, $$I = I_0 + M\left(\frac{L}{2}\right)^2$$

$$\Rightarrow \quad I = I_0 + \frac{ML^2}{4}$$

43 Four identical thin rods each of mass M and length l, form a square frame. Moment of inertia of this frame about an axis through the centre of the square and perpendicular to its plane is **[CBSE AIPMT 2009]**

(a) $\frac{4}{3}Ml^2$ (b) $\frac{2}{3}Ml^2$

(c) $\frac{13}{3}Ml^2$ (d) $\frac{1}{3}Ml^2$

Ans. *(a)*

Moment of inertia of rod about an axis through its centre of mass and perpendicular to rod = (mass of rod) × (perpendicular distance between two axes)

$$= \frac{Ml^2}{12} + M\left(\frac{l}{2}\right)^2 = \frac{Ml^2}{3}$$

Moment of inertia of the system

$$= \frac{Ml^2}{3} \times 4$$

$$= \frac{4}{3}Ml^2$$

44 A thin rod of length L and mass M is bent at its mid-point into two halves so that the angle between them is 90°. The moment of inertia of the bent rod about an axis passing through the bending point and perpendicular to the plane defined by the two halves of the rod is **[CBSE AIPMT 2008]**

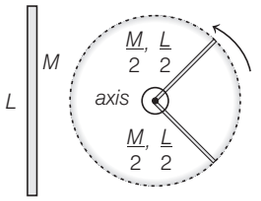
(a) $\frac{ML^2}{24}$ (b) $\frac{ML^2}{12}$

(c) $\frac{ML^2}{6}$ (d) $\frac{\sqrt{2}ML^2}{24}$

Ans. *(b)*

As the rod is bent into two equal halves, the mass and length of each half is $\frac{M}{2}$ and $\frac{L}{2}$ respectively.

The moment of inertia about an axis passing through its edge and perpendicular to the rod



$$= \frac{\text{Mass} \times (\text{length})^2}{3}$$

$$\therefore \quad I = 2 \times \frac{1}{3} \times \frac{M}{2}\left(\frac{L}{2}\right)^2 = \frac{ML^2}{12}$$

45 The ratio of the radii of gyration of a circular disc to that of a circular ring, each of same mass and radius, around their respective axes is **[CBSE AIPMT 2008]**

(a) $\sqrt{3}:\sqrt{2}$ (b) $1:\sqrt{2}$

(c) $\sqrt{2}:1$ (d) $\sqrt{2}:\sqrt{3}$

Ans. *(b)*

As we know that radius of gyration

$$k = \sqrt{\frac{I}{m}}$$

So, for two different cases

$$\frac{k_{ring}}{k_{disc}} = \sqrt{\frac{I_{ring}}{I_{disc}}} = \sqrt{\frac{MR^2}{\frac{1}{2}MR^2}}$$

$$\therefore \quad \frac{k_{ring}}{k_{disc}} = \sqrt{2} \Rightarrow \frac{k_{disc}}{k_{ring}} = \frac{1}{\sqrt{2}}$$

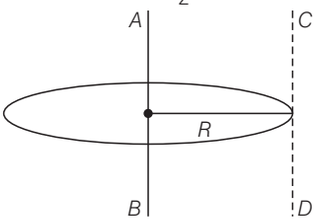
46 The moment of inertia of a uniform circular disc of radius R and mass M about an axis passing from the edge of the disc and normal to the disc is **[CBSE AIPMT 2006]**

(a) $\frac{1}{2}MR^2$ (b) MR^2 (c) $\frac{7}{2}MR^2$ (d) $\frac{3}{2}MR^2$

Ans. *(d)*

Moment of inertia of disc passing through its centre of gravity and perpendicular to its plane is

$$I_{AB} = \frac{1}{2}MR^2$$

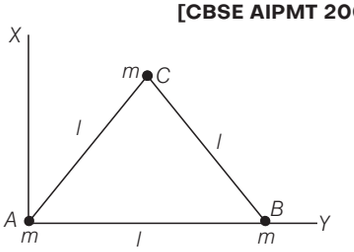


Using theorem of parallel axes, we have,

$$I_{CD} = I_{AB} + MR^2$$

$$= \frac{1}{2}MR^2 + MR^2 = \frac{3}{2}MR^2$$

47 Three particles, each of mass m grams situated at the vertices of an equilateral ΔABC of side l cm (as shown in the figure). The moment of inertia of the system about a line AX perpendicular to AB and in the plane of ABC in g-cm^2 units will be **[CBSE AIPMT 2004]**

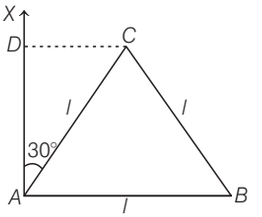


(a) $\left(\frac{3}{4}\right)ml^2$ (b) $2\,ml^2$

(c) $\left(\frac{5}{4}\right)ml^2$ (d) $\left(\frac{3}{2}\right)ml^2$

Ans. *(c)*

Moment of inertia of the system about AX is given by



$$\text{Moment of inertia} = m_A r_A^2 + m_B r_B^2 + m_C r_C^2$$

$$\begin{bmatrix} r_A = 0 \\ r_B = l \\ r_c = l\sin 30° \end{bmatrix}$$

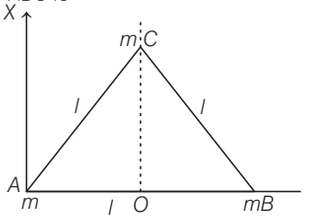
Moment of inertia

$$= m(0)^2 + m(l)^2 + m(l\sin 30°)^2$$

$$= ml^2 + \frac{ml^2}{4} = \frac{5}{4}ml^2$$

Alternative

Moment of inertia of a system about a line OC perpendicular to AB in the plane of ABC is



$$I_{CO} = m \times 0 + m \times \left(\frac{l}{2}\right)^2 + m \times \left(\frac{l}{2}\right)^2$$

$$\therefore \quad I_{CO} = \frac{ml^2}{4} + \frac{ml^2}{4} = \frac{ml^2}{2}$$

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Now, by applying parallel axes theorem

$$I_{AX} = I_{CO} + Mx^2$$

where, x = distance of AX from CO

M = total mass of system

$$I_{AX} = \frac{ml^2}{2} + 3m \times \left(\frac{l}{2}\right)^2$$

$$I_{AX} = \frac{ml^2}{2} + \frac{3ml^2}{4} = \frac{5}{4} ml^2$$

48 The ratio of the radii of gyration of a circular disc about a tangential axis in the plane of the disc and of a circular ring of the same radius about a tangential axis in the plane of the ring is **[CBSE AIPMT 2004]**

(a) 2 : 3 (b) 2 : 1
(c) $\sqrt{5} : \sqrt{6}$ (d) $1 : \sqrt{2}$

Ans. *(c)*

Moment of inertia of a disc and circular ring about a tangential axis in their planes are respectively. Momentum inertia of disc about tangential axis

$$I_d = \frac{5}{4} M_d R^2$$

Moment of inertia of ring about a tangential axis

$$I_r = \frac{3}{2} M_r R^2$$

but $I = Mk^2 \Rightarrow k = \sqrt{\frac{I}{M}}$

$$\therefore \quad \frac{k_d}{k_r} = \sqrt{\frac{I_d}{I_r} \times \frac{M_r}{M_d}}$$

or $$\frac{k_d}{k_r} = \sqrt{\frac{(5/4) M_d R^2}{(3/2) M_r R^2} \times \frac{M_r}{M_d}} = \sqrt{\frac{5}{6}}$$

$$\therefore \quad k_d : k_r = \sqrt{5} : \sqrt{6}$$

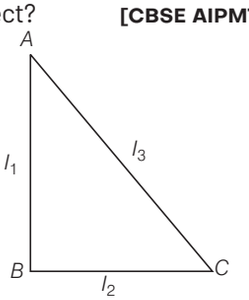
49 A circular disc is to be made using iron and aluminium. To keep its moment of inertia maximum about a geometrical axis, it should be so prepared that **[CBSE AIPMT 2002]**

(a) aluminium is at the interior and iron surrounds it
(b) iron is at the interior and aluminium surrounds it
(c) aluminium and iron layers are in alternate order
(d) sheet of iron is used at both external surfaces and aluminium sheet as inner material

Ans. *(a)*

Moment of inertia depends on distribution of mass and about axis of rotation. Density of iron is more than that of aluminium, therefore for moment of inertia to be maximum, the iron should be far away from the axis. Thus, aluminium should be at interior and iron surrounds it.

50 ABC is a right angled triangular plate of uniform thickness. The sides are such that $AB > BC$ as shown in figure. I_1, I_2, I_3 are moments of inertia about AB, BC and AC respectively. Then, which of the following relations is correct? **[CBSE AIPMT 2000]**



(a) $I_1 = I_2 = I_3$
(b) $I_2 > I_1 > I_3$
(c) $I_3 < I_2 < I_1$
(d) $I_3 > I_1 > I_2$

Ans. *(b)*

The moment of inertia of a body about an axis depends not only on the mass of the body, but also on the distribution of mass from the axis. For a given body, mass is same, so it will depend only on the distribution of mass from the axis.

The mass is farthest from axis BC, so I_2 is maximum. Mass is nearest to axis AC, so I_3 is minimum.

Hence, the correct sequence will be

$$I_2 > I_1 > I_3$$

NOTE

In a rotational motion, moment of inertia is also known as rotational inertia.

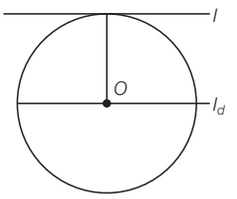
51 The moment of inertia of a disc of mass M and radius R about a tangent to its rim in its plane is **[CBSE AIPMT 1999]**

(a) $\frac{2}{3} MR^2$ (b) $\frac{3}{2} MR^2$
(c) $\frac{4}{5} MR^2$ (d) $\frac{5}{4} MR^2$

Ans. *(d)*

Moment of inertia of a disc about its diameter is

$$I_d = \frac{1}{4} MR^2$$



Now, according to perpendicular axis theorem, moment of inertia of disc about a tangent passing through rim and in the plane of disc is

$$I = I_d + MR^2 = \frac{1}{4} MR^2 + MR^2 = \frac{5}{4} MR^2$$

52 ABC is a triangular plate of uniform thickness. The sides are in the ratio shown in the figure. I_{AB}, I_{BC} and I_{CA} are the moments of inertia of the plate about AB, BC and CA as axes respectively. Which one of the following relations is correct? **[CBSE AIPMT 1995]**

(a) $I_{AB} > I_{BC}$ (b) $I_{BC} > I_{AC}$
(c) $I_{AB} + I_{BC} = I_{CA}$ (d) I_{CA} is maximum

Ans. *(b)*

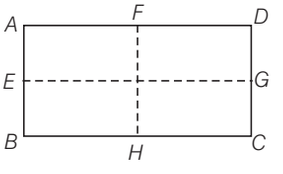
Moment of inertia of the triangular plate is maximum about the shortest side because effective distance of mass distribution about this side is maximum. Since, distances of centre of mass from the sides are related as

$$x_{BC} < x_{AB} < x_{AC}$$

Therefore

$$I_{BC} > I_{AB} > I_{AC} \quad \text{or} \quad I_{BC} > I_{AC}$$

53 In a rectangle $ABCD$ ($BC = 2AB$). The moment of inertia is minimum along axis through **[CBSE AIPMT 1993]**



(a) BC (b) BD
(c) HF (d) EG

Ans. *(d)*

Concept Magnitude of moment of inertia depends on the distribution of mass taken from the axis.

From the axis EG, the distribution of masses is at minimum distance while from the axis BD the distribution of masses is at maximum distance. Hence, the moment of inertia is minimum along axis through EG.

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TOPIC 3
Kinematics and Dynamics of Rotational Motion

54 The angular speed of the wheel of a vehicle is increased from 360 rpm to 1200 rpm in 14 s. Its angular acceleration is **[NEET (Oct.)2020]**

(a) 2π rad/s^2 (b) 28π rad/s^2
(c) 120π rad/s^2 (d) 1 rad/s^2

Ans. *(a)*

Initial angular speed of wheel,

$$\omega_0 = 2\pi f_0 = 2\pi \times \frac{360}{60}\ \text{rad/s}$$
$$= 12\pi\ \text{rad/s}$$

Final angular speed of wheel,

$$\omega = 2\pi f$$
$$= 2\pi \times \frac{1200}{60}\ \text{rad/s} = 40\pi\ \text{rad/s}$$
$$t = 14\ \text{s}$$

From the equation of rotational motion,

$$\omega = \omega_0 + \alpha t$$
$$\Rightarrow \quad \alpha = \frac{\omega - \omega_0}{t}$$
$$= \frac{40\pi - 12\pi}{14} = \frac{28\pi}{14} = 2\pi\ \text{rad/s}^2$$

55 A particle starting from rest, moves in a circle of radius 'r'. It attains a velocity of v_0 m/s in the n^{th} round. Its angular acceleration will be **[NEET (Odisha) 2019]**

(a) $\frac{v_0}{n}$ rad/s^2 (b) $\frac{v_0^2}{2\pi nr^2}$ rad/s^2
(c) $\frac{v_0^2}{4\pi nr^2}$ rad/s^2 (d) $\frac{v_0^2}{4\pi nr}$ rad/s^2

Ans. *(c)*

From third equation of motion for circular motion

$$\omega^2 - \omega_0^2 = 2\alpha\theta \qquad \ldots(i)$$

where, ω = final angular velocity of particle
ω_0 = initial angular velocity
α = angular acceleration and
θ = angular displacement

Here, $\omega = \frac{v_0}{r}$ rad/s (where, r radius of the circle)

$\omega_0 = 0$ (initially particle is at rest)
$\theta = 2\pi n$ (for n rounds)

Substituting these values in Eq. (i), we get

$$\left(\frac{v_0}{r}\right)^2 - 0 = 2\alpha(2\pi n)$$
$$\Rightarrow \quad \alpha = \frac{v_0^2}{4\pi nr^2}\ \text{rad/s}^2$$

56 A solid cylinder of mass 2 kg and radius 50 cm rolls up an inclined plane of angle inclination 30°. The centre of mass of cylinder has speed of 4 m/s. The distance travelled by the cylinder on the inclined surface will be : (Take $g = 10\ \text{m/s}^2$) **[NEET (Odisha) 2019]**

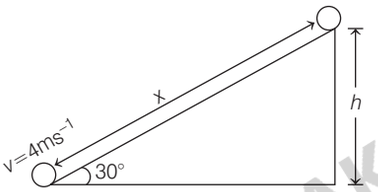
(a) 2.2 m (b) 1.6 m
(c) 1.2 m (d) 2.4 m

Ans. *(d)*

When a body rolls i.e. have rotational motion, the total kinetic energy of the system will be

$$KE = \frac{1}{2}mv^2\left(1 + \frac{k^2}{R^2}\right)$$

where, m = mass of body, v = velocity and k = radius of gyration



Given, $m = 2\ \text{kg}, \theta = 30°, v = 4\ \text{ms}^{-1}$

Let h be the height of the inclined plane, then from law of conservation of energy,

$$KE = PE$$
$$\frac{1}{2}mv^2\left(1 + \frac{k^2}{R^2}\right) = mgh$$

Substituting the given values in the above equation, we get

$$\frac{1}{2} \times 2 \times 16\left(1 + \frac{1}{2}\right) = 2 \times 10 \times h$$

$$\left[\because \text{For cylinder } \frac{k^2}{R^2} = \frac{1}{2}\right]$$

$$\Rightarrow \qquad 8 \times \frac{3}{2} = 10\,h \ \Rightarrow\ h = 1.2\ \text{m}$$

From the above diagram

$$\sin\theta = \frac{h}{x}$$
$$\Rightarrow x = \frac{h}{\sin\theta} = \frac{1.2}{\sin 30°} = 1.2 \times 2 = 2.4\ \text{m}$$
$$\left[\because \sin 30° = \frac{1}{2}\right]$$

57 A disc of radius 2 m and mass 100 kg rolls on a horizontal floor. Its centre of mass has speed of 20 cm/s. How much work is needed to stop it? **[NEET (National) 2019]**

(a) 30 kJ (b) 2 J
(c) 1 J (d) 3 J

Ans. *(d)*

Given, radius $R = 2\ \text{m}$
mass, $m = 100$ kg and
v_{CM} (velocity centre of mass) $= v = 20\ \text{cm/s} = 20 \times 10^{-2}$ m/s.

Then, according to work energy theorem, the work done in stopping the disc is equal to the change in its kinetic energy, i.e.

$$W = \text{KE}_f - \text{KE}_i$$

As, the disc stops at the end, so final velocity is zero. Thus, $\text{KE}_f = 0$

Since, the disc is rolling so, its initial kinetic energy would have both rotational and translational kinetic energy component.

$$\text{KE}_i = \text{KE}_R + \text{KE}_T = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2$$
$$= \frac{1}{2}\left(\frac{1}{2}mR^2\right)\omega^2 + \frac{1}{2}mv^2$$
$$\left[\because \text{for disc}, I = \frac{1}{2}mR^2\right]$$
$$= \frac{1}{4}mR^2\omega^2 + \frac{1}{2}mv^2$$
$$= \frac{1}{4}mR^2\frac{v^2}{R^2} + \frac{1}{2}mv^2 \qquad [\because v = r\omega]$$
$$= \frac{3}{4}mv^2$$

$$\therefore W = |\text{KE}_i| = \frac{3}{4}mv^2$$

Substituting the given values, we get

$$W = \frac{3}{4} \times 100 \times (20 \times 10^{-2})^2$$
$$= \frac{3}{4} \times 400 \times 100 \times 10^{-4} = 3\ \text{J}$$

58 A solid cylinder of mass 2 kg and radius 4 cm is rotating about its axis at the rate of 3 rpm. The torque required to stop after 2π revolutions is **[NEET (National) 2019]**

(a) 2×10^{-3} N-m (b) 12×10^{-4} N-m
(c) 2×10^{6} N-m (d) 2×10^{-6} N-m

Ans. *(d)*

Key Idea *According to work-energy theorem, the change in kinetic energy of a particle is the amount of work done on the particle to move, i.e.*

$$W = -\Delta\text{KE} = \text{KE}_f - \text{KE}_i$$

Given, mass of cylinder, $m = 2$ kg
radius of cylinder, $r = 4\ \text{cm} = 4 \times 10^{-2}$ m
rotational velocity, $\omega = 3$ rpm
$= 3 \times \frac{2\pi}{60} = \frac{\pi}{10}$ rad/s and $\theta = 2\pi$ revolution
$= 2\pi \times 2\pi = 4\pi^2$ rad.

The work done in rotating an object by an angle θ from rest is given by $W = \tau\theta$

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As the cylinder is brought to rest, so the work done will be negative.

According to work-energy theorem,

Work done = Change in rotational kinetic energy

$$-\tau\theta = \frac{1}{2}I\omega_f^2 - \frac{1}{2}I\omega_i^2 = \frac{1}{2}I(\omega_f^2 - \omega_i^2)$$

$$\Rightarrow \quad \tau = \frac{I(-\omega_i^2)}{2\theta} \qquad [\because \omega_f = 0]$$

$$= \frac{1}{2}\left(\frac{1}{2}mr^2\right)\frac{\omega_i^2}{\theta}$$

$$\left[I = \frac{1}{2}MR^2 \text{ (for cylinder)}\right]$$

$$= \frac{1}{4}mr^2\frac{\omega^2}{\theta} \qquad [\because \omega_i = \omega]$$

$$= \frac{1}{4}\times 2\times(4\times10^{-2})^2\times\left(\frac{\pi}{10}\right)^2\times\frac{1}{4\pi^2}$$

$$= \frac{1}{4}\times 2\times 16\times10^{-4}\times\frac{\pi^2}{100}\times\frac{1}{4\pi^2}$$

$$= \frac{2}{100}\times10^{-4} = 2\times10^{-6} \text{ N-m}$$

59 Three objects, *A* : (a solid sphere), *B* : (a thin circular disk) and *C* : (a circular ring), each have the same mass *M* and radius *R*. They all spin with the same angular speed ω about their own symmetry axes. The amounts of work (*W*) required to bring them to rest, would satisfy the relation **[NEET 2018]**

(a) $W_B > W_A > W_C$ (b) $W_A > W_B > W_C$

(c) $W_C > W_B > W_A$ (d) $W_A > W_C > W_B$

Ans. *(c)*

Work done required to bring an object to rest is given as

$$W = \frac{1}{2}I\omega^2$$

where, *I* is the moment of inertia and ω is the angular velocity.

Since, here all the objects spin with the same ω, this means,

$$W \propto I$$

As, I_A (for a solid sphere) $= \frac{2}{5}MR^2$

I_B (for a thin circular disk) $= \frac{1}{2}MR^2$

I_C (for a circular ring) $= MR^2$

$$\therefore \quad W_A : W_B : W_C = I_A : I_B : I_C$$

$$= \frac{2}{5}MR^2 : \frac{1}{2}MR^2 : MR^2$$

$$= \frac{2}{5} : \frac{1}{2} : 1$$

$$= 4 : 5 : 10$$

$$\Rightarrow \quad W_A < W_B < W_C$$

60 A solid sphere is rotating freely about its symmetry axis in free space. The radius of the sphere is increased keeping its mass same. Which of the following physical quantities would remain constant for the sphere? **[NEET 2018]**

(a) Rotational kinetic energy

(b) Moment of inertia

(c) Angular velocity

(d) Angular momentum

Ans. *(d)*

Moment of inertia of a rotating solid sphere about its symmetrical (diametric) axis is given as, $I = \frac{2}{5}mR^2$

Rotational kinetic energy of solid sphere is

$$K_r = \frac{1}{2}I\omega^2$$

$$= \frac{1}{2}\times\frac{2}{5}mR^2\omega^2 = \frac{1}{5}mR^2\omega^2$$

Angular velocity, $\omega = V_{cm}R$

As, we know that external torque,

$$\tau_{ext} = \frac{dL}{dt}$$

where, *L* is the angular momentum.

Since, in the given condition, $\tau_{ext} = 0$

$$\Rightarrow \quad \frac{dL}{dt} = 0 \text{ or } L = \text{constant}$$

Hence, when the radius of the sphere is increased keeping its mass same, only the angular momentum remains constant. But other quantities like moment of inertia, rotational kinetic energy and angular velocity changes.

61 A solid sphere is in rolling motion. In rolling motion, a body possesses translational kinetic energy (K_t) as well as rotational kinetic energy (K_r) simultaneously. The ratio $K_t : (K_t + K_r)$ for the sphere is **[NEET 2018]**

(a) 10 : 7 (b) 5 : 7

(c) 7 : 10 (d) 2 : 5

Ans. *(b)*

Translational kinetic energy of a rolling body is

$$K_t = \frac{1}{2}mv_{CM}^2 \qquad ...(i)$$

Total kinetic energy of a rolling body

$$= K_t + K_r = \text{Rotational KE} + \text{Translational KE}$$

$$= \frac{1}{2}I\omega^2 + \frac{1}{2}mv_{CM}^2 \qquad ...(ii)$$

For a solid sphere, moment of inertia about its diametric axis, $I = \frac{2}{5}MR^2$

Substituting the value of *I* in Eq. (ii), we get

$$K_t + K_r = \frac{1}{2}\left(\frac{2}{5}MR^2\right)\omega^2 + \frac{1}{2}mv_{CM}^2$$

$$= \frac{1}{2}\left(\frac{2}{5}MR^2\right)\left(\frac{v_{CM}}{R}\right)^2 + \frac{1}{2}mv_{CM}^2 \qquad [\because v_{CM} = R\omega]$$

$$= \frac{1}{5}mv_{CM}^2 + \frac{1}{2}mv_{CM}^2$$

$$= \left(\frac{1}{5} + \frac{1}{2}\right)mv_{CM}^2$$

$$= \frac{7}{10}mv_{CM}^2 \qquad ...(iii)$$

$$\therefore \quad \text{Ratio, } \frac{K_t}{K_t + K_r} = \frac{\frac{1}{2}mv_{CM}^2}{\frac{7}{10}mv_{CM}^2}$$

$$= \frac{1}{2}\times\frac{10}{7} = \frac{5}{7}$$

$$\therefore \quad K_t : K_t + K_r = 5 : 7$$

Alternate Method

Suppose, moment of inertia,

$$I = xMR^2 \qquad ...(i)$$

For solid sphere, moment of inertia,

$$I = \frac{2}{5}MR^2 \qquad ...(ii)$$

Thus, from Eqs. (i) and (ii), we get

$$x = \frac{2}{5}$$

Since, the ratio of translational energy to the total energy can be written as

$$\frac{K_t}{K_t + K_r} = \frac{\frac{1}{2}mv_{CM}^2}{\frac{1}{2}mv_{CM}^2\left(1 + \frac{k^2}{R^2}\right)} \qquad ...(iii)$$

where, *k* is called the radius of gyration.

As, $K = \sqrt{\frac{I}{m}}$ or $K^2 = \frac{I}{m}$

From Eq. (i), we get

$$K^2 = \frac{xmR^2}{m} = xR^2$$

Substituting the value of K^2 in Eq. (iii), we get

$$\frac{K_t}{K_t + K_r} = \frac{1}{\left(1 + \frac{xR^2}{R^2}\right)} = \frac{1}{1+x}$$

Here, $x = \frac{2}{5}$

$$\Rightarrow \quad \frac{K_t}{K_t + K_r} = \frac{1}{1 + 2/5} = \frac{5}{7}$$

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62 Two discs of same moment of inertia rotating about their regular axis passing through centre and perpendicular to the plane of disc with angular velocities ω_1 and ω_2. They are brought into contact face to face coinciding the axis of rotation. The expression for loss of energy during this process is **[NEET 2017]**

(a) $\frac{1}{2}I(\omega_1+\omega_2)^2$ (b) $\frac{1}{4}I(\omega_1-\omega_2)^2$

(c) $I(\omega_1-\omega_2)^2$ (d) $\frac{I}{8}(\omega_1-\omega_2)^2$

Ans. *(b)*

Thinking Process When no external torque acts on system then, angular momentum of system remains constant.

Angular momentum before contact

$$=I_1\omega_1+I_2\omega_2$$

Angular momentum after the discs brought into contact

$$=I_{net}\omega=(I_1+I_2)\omega$$

So, final angular speed of system $=\omega$

$$=\frac{I_1\omega_1+I_2\omega_2}{I_1+I_2}$$

Now, to calculate loss of energy, we subtract initial and final energies of system.

$\Rightarrow$ Loss of energy

$$=\frac{1}{2}I\omega_1^2+\frac{1}{2}I\omega_2^2-\frac{1}{2}(2I)\omega^2$$

$$=\frac{1}{4}I(\omega_1-\omega_2)^2$$

63 Two rotating bodies *A* and *B* of masses *m* and 2*m* with moments of inertia I_A and $I_B (I_B > I_A)$ have equal kinetic energy of rotation. If L_A and L_B be their angular momenta respectively, then **[NEET 2016]**

(a) $L_A=\frac{L_B}{2}$

(b) $L_A=2L_B$ (c) $L_B>L_A$

(d) $L_A>L_B$

Ans. *(c)*

As we know that, the kinetic energy of a rotating body,

$$KE=\frac{1}{2}I\omega^2=\frac{1}{2}\frac{I^2\omega^2}{I}=\frac{L^2}{2I}$$

Also, angular momentum, $L=I\omega$

Thus, $K_A=K_B$

$$\Rightarrow \frac{1}{2}\frac{L_A^2}{I_A}=\frac{1}{2}\frac{L_B^2}{I_B}$$

$$\Rightarrow \left(\frac{L_A}{L_B}\right)^2=\frac{I_A}{I_B}\Rightarrow\frac{L_A}{L_B}=\sqrt{\frac{I_A}{I_B}}$$

$$L\propto\sqrt{I}$$

$$\therefore \quad L_A<L_B \qquad [\because I_B>I_A]$$

64 A disc and a sphere of same radius but different masses roll off on two inclined planes of the same altitude and length. Which one of the two objects gets to the bottom of the plane first? **[NEET 2016]**

(a) Sphere

(b) Both reach at the same time

(c) Depends on their masses

(d) Disc

Ans. *(a)*

Acceleration of an object rolling down an inclined plane is given by

$$a=\frac{g\sin\theta}{1+I/mr^2}$$

where, θ = angle of inclination of the inclined plane

m = mass of the object

I = moment of inertia about the axis through centre of mass

For disc, $\frac{I}{mr^2}=\frac{1/2\,mr^2}{mr^2}=\frac{1}{2}$

For solid sphere, $\frac{I}{mr^2}=\frac{2/5mr^2}{mr^2}=\frac{2}{5}$

For hollow sphere, $\frac{I}{mr^2}=\frac{2/3mr^2}{mr^2}=\frac{2}{3}$

$$\therefore \quad a_{disc}=\frac{g\sin\theta}{1+\frac{1}{2}}=\frac{2}{3}g\sin\theta=0.66$$

$$g\sin\theta\; a_{solid\ sphere}=\frac{g\sin\theta}{1+\frac{2}{5}}=\frac{5}{7}g\sin\theta$$

$$=0.71\,g\sin\theta$$

$$a_{hollow\ sphere}=\frac{g\sin\theta}{1+\frac{2}{3}}=\frac{3}{5}g\sin\theta$$

$$=0.6\,g\sin\theta$$

Clearly, $a_{solid\ sphere}>a_{disk}>a_{hollow\ sphere}$

Type of sphere is not mentioned in the question. Therefore, we will assume the given sphere as solid sphere.

$$\therefore \quad a_{solid\ sphere}=a_{hollow\ sphere}>a_{disk}$$

65 A solid sphere of mass *m* and radius *R* is rotating about its diameter. A solid cylinder of the same mass and same radius is also rotating about its geometrical axis with an angular speed twice that of the sphere. The ratio of their kinetic energies of rotation $(E_{sphere}/E_{cylinder})$ will be **[NEET 2016]**

(a) 2 : 3 (b) 1 : 5 (c) 1 : 4 (d) 3 : 1

Ans. *(b)*

Key Idea *KE of a rotating rigid body,*

$$KE=\frac{1}{2}I\omega^2$$

$$\therefore \text{ KE of sphere, } K_S=\frac{1}{2}I\omega_1^2=\frac{1}{2}\frac{2}{5}mR^2\omega_1^2$$

$$=\frac{1}{5}mR^2\omega_1^2$$

KE of cylinder, $K_C=\frac{1}{2}\frac{1}{2}mR^2\omega_2^2$

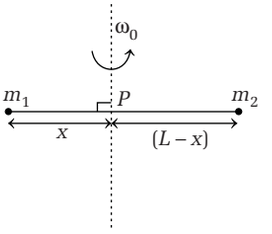
$$=\frac{1}{4}mR^2\omega_2^2$$

$$\therefore \quad \frac{K_S}{K_C}=\frac{\frac{mR^2\omega_1^2}{5}}{\frac{mR^2\omega_2^2}{4}}$$

$$=\frac{4}{5}\frac{\omega_1^2}{\omega_2^2}=\frac{4}{5}\frac{\omega_1^2}{(2\omega_1)^2}$$

$$=\frac{1}{5} \qquad (\text{given, } \omega_2=2\omega_1)$$

66 Point masses m_1 and m_2 are placed at the opposite ends of a rigid rod of length *L* and negligible mass. The rod is to be set rotating about an axis perpendicular to it. The position of point *P* on this rod through which the axis should pass, so that the work required to set the rod rotating with angular velocity ω_0 is minimum, is given by **[CBSE AIPMT 2015]**



(a) $x=\frac{m_1L}{m_1+m_2}$ (b) $x=\frac{m_1}{m_2}L$

(c) $x=\frac{m_2}{m_1}L$ (d) $x=\frac{m_2L}{m_1+m_2}$

Ans. *(d)*

As two point masses m_1 and m_2 are placed at opposite ends of a rigid rod of length *L* and negligible mass as shown in figure.

Total moment of inertia of the rod

$I=m_1x^2+m_2(L-x)^2$

$I=m_1x^2+m_2L^2+m_2x^2-2m_2Lx$

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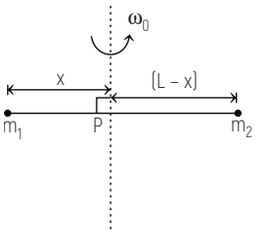


As, I is minimum i.e.

$$\frac{dI}{dx} = 2m_1 x + 0 + 2xm_2 - 2m_2 L = 0$$

$$\Rightarrow \quad x(2m_1 + 2m_2) = 2m_2 L$$

$$\Rightarrow \quad x = \frac{m_2 L}{m_1 + m_2}$$

When I is minimum, then work done on rotating a rod $1/2\, I\omega^2$ with angular velocity ω_0 will be minimum.

Shortcut Way *The position of point P on rod through which the axis should pass, so that the work required to set the rod rotating with minimum angular velocity ω_0 is their centre of mass, we have*

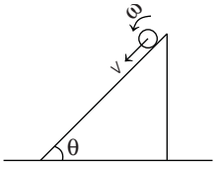
$$m_1 x = m_2 (L - x) \Rightarrow x = \frac{m_2 L}{m_1 + m_2}$$

67 The ratio of the accelerations for a solid sphere (mass m and radius R) rolling down an incline of angle θ without slipping and slipping down the incline without rolling is **[CBSE AIPMT 2014]**

(a) 5 : 7 (b) 2 : 3
(c) 2 : 5 (d) 7 : 5

Ans. ***(a)***

A solid sphere rolling without slipping down an inclined plane



In this case, $a_1 = \dfrac{g\sin\theta}{1 + \dfrac{k^2}{R^2}} = \dfrac{g\sin\theta}{1 + \dfrac{(2/5)R^2}{R^2}}$

$$\left[\because \text{for solid sphere}, k^2 = \frac{2}{5}R^2\right]$$

$$= \frac{g\sin\theta}{7/5} \Rightarrow a_1 = \frac{5}{7} g\sin\theta$$

For a sphere slipping down an inclined plane

$$\Rightarrow \quad a_2 = g\sin\theta \Rightarrow \frac{a_1}{a_2} = \frac{5/7\, g\sin\theta}{g\sin\theta}$$

$$\Rightarrow \quad \frac{a_1}{a_2} = \frac{5}{7}$$

68 A small object of uniform density rolls up a curved surface with an initial velocity v'. It reaches upto a maximum height of $\dfrac{3v^2}{4g}$ with respect to the initial position. The object is **[NEET 2013]**

(a) ring (b) solid sphere
(c) hollow sphere (d) disc

Ans. ***(d)***

As, $$v = \sqrt{\frac{2gh}{1 + \dfrac{k^2}{r^2}}}$$

Given, $$h = \frac{3v^2}{4g}$$

So, $$v^2 = \frac{2gh}{1 + \dfrac{k^2}{r^2}}$$

$$= \frac{2g\,3v^2}{4g\left(1 + \dfrac{k^2}{r^2}\right)} = \frac{6\,gv^2}{4\,g\left(1 + \dfrac{k^2}{r^2}\right)}$$

$$1 = \frac{3}{2\left(1 + \dfrac{k^2}{r^2}\right)}$$

or $$1 + \frac{k^2}{r^2} = \frac{3}{2} \quad \text{or} \quad \frac{k^2}{r^2} = \frac{3}{2} - 1 = \frac{1}{2}$$

$$k^2 = \frac{1}{2}r^2 \text{ (Equation of disc)}$$

Hence, the object is disc.

69 A circular disc of moment of inertia I_t is rotating in a horizontal plane, about its symmetry axis, with a constant angular speed ω_i. Another disc of moment of inertia I_b is dropped coaxially onto the rotating disc. Initially the second disk has zero angular speed. Eventually both the discs rotate with a constant angular speed ω_f. The energy lost by initially rotating disc due to friction is **[CBSE AIPMT 2010]**

(a) $\dfrac{1}{2}\dfrac{I_b^2}{(I_t + I_b)}\omega_i^2$ (b) $\dfrac{1}{2}\dfrac{I_t^2}{(I_t + I_b)}\omega_i^2$

(c) $\dfrac{1}{2}\dfrac{I_b - I_t}{(I_t + I_b)}\omega_i^2$ (d) $\dfrac{1}{2}\dfrac{I_b\, I_t}{(I_t + I_b)}\omega_i^2$

Ans. ***(d)***

Loss of energy is given by

$$\Delta E = \frac{1}{2} I_t\, \omega_i^2 - \frac{1}{2}\frac{I_t^2\, \omega_i^2}{(I_t + I_b)}$$

$$= \frac{1}{2}\frac{I_b\, I_t\, \omega_i^2}{(I_t + I_b)}$$

70 A wheel has angular acceleration of 3 rad / s^2 and an initial angular speed of 2 rad/s. In a time of 2 s, it has rotated through an angle (in radian) of **[CBSE AIPMT 2007]**

(a) 6 (b) 10 (c) 12 (d) 4

Ans. ***(b)***

By definition $\alpha = \dfrac{d\omega}{dt}$

i.e. $$d\omega = \alpha\, dt$$

So, if in time t the angular speed of a body changes from ω_0 to ω

$$\int_{\omega_0}^{\omega} d\omega = \int_0^t \alpha\, dt$$

If α is constant

$$\omega - \omega_0 = \alpha t \quad \text{or} \quad \omega = \omega_0 + \alpha t \quad \text{...(i)}$$

Now, as by definition $\omega = \dfrac{d\theta}{dt}$

Eq. (i) becomes $\dfrac{d\theta}{dt} = \omega_0 + \alpha t$

i.e. $$d\theta = (\omega_0 + \alpha t)\, dt$$

So, if in time t angular displacement is θ.

$$\int_0^{\theta} d\theta = \int_0^{t} (\omega_0 + \alpha t)\, dt$$

or $$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \quad \text{...(ii)}$$

Given $$\alpha = 3 \text{ rad/s}^2$$

$$\omega_0 = 2 \text{ rad/s}, \; t = 2 \text{ s}$$

Here $$\theta = 2 \times 2 + \frac{1}{2} \times 3 \times (2)^2$$

or $$\theta = 4 + 6 = 10 \text{ rad}$$

Alternative

As we know that equation of circular motion

$$\theta = \omega t + \frac{1}{2}\alpha t^2$$

(where symbols have their usual meaning)

Putting the value of ω, t, α from question.

So, $$\theta = 2 \times 2 + \frac{1}{2} \times 3 \times 2 \times 2 = 10 \text{ rad}$$

71 Two bodies have their moments of inertia I and $2I$ respectively about their axis of rotation. If their kinetic energies of rotation are equal, their angular momenta will be in the ratio **[CBSE AIPMT 2005]**

(a) 1 : 2 (b) $\sqrt{2}$: 1 (c) 2 : 1 (d) 1 : $\sqrt{2}$

Ans. ***(d)***

Concept As for linear motion $KE = \dfrac{p^2}{2m}$

Similarly, for rotational motion $KE_{rot} = \dfrac{L^2}{2I}$

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As said, $(KE)_{rot}$ remains same.

i.e. $\frac{1}{2} I_1 \omega_1^2 = \frac{1}{2} I_2 \omega_2^2$

$\Rightarrow \frac{1}{2I_1}(I_1\omega_1)^2 = \frac{1}{2I_2}(I_2\omega_2)^2$

$\Rightarrow \frac{L_1^2}{I_1} = \frac{L_2^2}{I_2}$

$\Rightarrow \frac{L_1}{L_2} = \sqrt{\frac{I_1}{I_2}}$

but $I_1 = I, I_2 = 2I$

$\therefore \frac{L_1}{L_2} = \sqrt{\frac{I}{2I}} = \frac{1}{\sqrt{2}}$

or $L_1 : L_2 = 1 : \sqrt{2}$

72 A ball rolls without slipping. The radius of gyration of the ball about an axis passing through its centre of mass is k. If radius of the ball be R, then the fraction of total energy associated with its rotational energy will be **[CBSE AIPMT 2003]**

(a) $\frac{k^2}{k^2+R^2}$ (b) $\frac{R^2}{k^2+R^2}$

(c) $\frac{k^2+R^2}{R^2}$ (d) $\frac{k^2}{R^2}$

Ans. *(a)*

Kinetic energy of rotation is

$$K_{rot} = \frac{1}{2} I\omega^2 = \frac{1}{2} Mk^2 \frac{v^2}{R^2} \quad \left[K = \sqrt{\frac{I}{M}}\right]$$

where, k is radius of gyration.

Kinetic energy of translation is

$$K_{trans} = \frac{1}{2} Mv^2$$

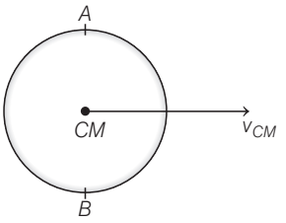
Thus, total energy

$$E = K_{rot} + K_{trans}$$
$$= \frac{1}{2} Mk^2 \frac{v^2}{R^2} + \frac{1}{2} Mv^2$$
$$= \frac{1}{2} Mv^2 \left(\frac{k^2}{R^2} + 1\right)$$
$$= \frac{1}{2} \frac{Mv^2}{R^2}(k^2 + R^2)$$

Hence, $\frac{K_{rot.}}{E} = \frac{\frac{1}{2} Mk^2 \frac{v^2}{R^2}}{\frac{1}{2}\frac{Mv^2}{R^2}(k^2+R^2)}$

$$= \frac{k^2}{k^2+R^2}$$

73 A wheel of bicycle is rolling without slipping on a level road. The velocity of the centre of mass is v_{CM}, then true statement is **[CBSE AIPMT 2001]**



(a) The velocity of point A is $2v_{CM}$ and velocity of point B is zero

(b) The velocity of point A is zero and velocity of point B is $2v_{CM}$

(c) The velocity of point A is $2v_{CM}$ and velocity of point B is $-v_{CM}$

(d) The velocities of both A and B are v_{CM}

Ans. *(a)*

Similarly, velocity of point A is given by

v_A = velocity of centre of mass (v_{CM}) + Linear velocity of point $A(R\omega)$

$$= v_{CM} + v_{CM} \quad (\because v_{CM} = R\omega)$$
$$= 2v_{CM}$$

Velocity of point B is,

$$v_B = v_{CM} - R\omega = v_{CM} - v_{CM} = 0$$

Thus, the velocity of point A is $2v_{CM}$ and velocity of point B is zero.

74 If a flywheel makes 120 rev/min, then its angular speed will be **[CBSE AIPMT 1996]**

(a) 8π rad/s (b) 6π rad/s

(c) 4π rad/s (d) 2π rad/s

Ans. *(c)*

Angular velocity of flywheel is given by

$$\omega = 2\pi\nu$$

where, ν is number of revolutions per second or frequency of revolution

Here, $\nu = 120$ rev/min

$\therefore \omega = \frac{2\pi \times 120}{60} = 4\pi$ rad/s

75 The angular speed of an engine wheel making 90 rev/min is **[CBSE AIPMT 1995]**

(a) 1.5π rad/s (b) 3π rad/s

(c) 4.5π rad/s (d) 6π rad/s

Ans. *(b)*

Angular velocity of an object in circular motion is defined as the time rate of change of its angular displacement.

$\therefore \omega = \frac{\theta}{t} = \frac{2\pi}{T} = 2\pi\nu \quad \left(\because T = \frac{1}{\nu}\right)$

Number of revolutions made by the engine wheel $(\nu) = 90$/min.

$\therefore$ Angular velocity of the engine wheel

$$\omega = \frac{2\pi\nu}{60} = \frac{2\pi \times 90}{60} = 3\pi \text{ rad/s}$$

76 A spherical ball rolls on a table without slipping. Then, the fraction of its total energy associated with rotation is **[CBSE AIPMT 1994]**

(a) $\frac{2}{5}$ (b) $\frac{2}{7}$ (c) $\frac{3}{5}$ (d) $\frac{3}{7}$

Ans. *(b)*

Concept The total kinetic energy of the ball rolling on a table without slipping is equal to its rotational kinetic energy and translational kinetic energy. Total kinetic energy of spherical ball is given by

K = Kinetic energy rotational (K_{rot}) + Kinetic energy translational (K_{trans})

$$= \frac{1}{2} I\omega^2 + \frac{1}{2} mv^2$$

For sphere, moment of inertia about its diameter $I = \frac{2}{5} mr^2$

$\therefore K = \frac{1}{2}\left(\frac{2}{5} mr^2\right)\omega^2 + \frac{1}{2} mv^2$

$$= \frac{1}{5} mr^2 \omega^2 + \frac{1}{2} mv^2$$
$$= \frac{1}{5} mv^2 + \frac{1}{2} mv^2 \quad (\text{as } v = r\omega)$$
$$= \frac{7}{10} mv^2$$

$\therefore \frac{K_r}{K} = \frac{\frac{1}{5} mv^2}{\frac{7}{10} mv^2} = \frac{2}{7}$

77 A thin uniform circular ring is rolling down an inclined plane of inclination 30° without slipping. Its linear acceleration along the inclined plane will be **[CBSE AIPMT 1994]**

(a) $\frac{g}{2}$ (b) $\frac{g}{3}$ (c) $\frac{g}{4}$ (d) $\frac{2g}{3}$

Ans. *(c)*

Acceleration of the centre of mass of the rolling body is given by

$$a = \frac{g\sin\theta}{1 + \left(\frac{I}{MR^2}\right)}$$

Moment of inertia of the ring about an axis perpendicular to the plane of the ring and passing through its centre is given by

$$I = MR^2$$

$\therefore a = \frac{g\sin\theta}{1 + MR^2/MR^2}$

$$= \frac{g\sin 30°}{1+1} = \frac{g}{4}$$

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78 A solid sphere, disc and solid cylinder all of the same mass and made of the same material are allowed to roll down (from rest) on the inclined plane, then **[CBSE AIPMT 1993]**

(a) solid sphere reaches the bottom first
(b) solid sphere reaches the bottom last
(c) disc will reach the bottom first
(d) all reach the bottom at the same time

Ans. *(a)*

Let us consider that solid sphere, disc and solid cylinder are rolling on an inclined plane. M, I and R be mass, moment of inertia and radius of the rolling section in each case.

(i) **Solid sphere** The moment of inertia of a solid sphere about its diameter is given by

$$I = \frac{2}{5}MR^2 \text{ or } K = \frac{I}{MR^2} = \frac{2}{5}$$

As from the concept, acceleration

$$a = \frac{g\sin\theta}{1+K}$$

So, $$a = \frac{g\sin\theta}{1+\frac{2}{5}} = \frac{5}{7}g\sin\theta$$

(ii) **Disc** The moment of inertia of disc about an axis perpendicular to the plane of disc and passing through its centre is given by

$$I = \frac{1}{2}MR^2$$

or $$\frac{I}{MR^2} = \frac{1}{2}$$

$$\therefore \quad a = \frac{g\sin\theta}{1+\frac{1}{2}} = \frac{2}{3}g\sin\theta$$

(iii) **Solid cylinder** The moment of inertia of a cylinder about the axis passing through its centre and perpendicular to its plane is given by

$$I = \frac{1}{2}MR^2$$

or $$\frac{I}{MR^2} = \frac{1}{2}$$

$$\therefore \quad a = \frac{g\sin\theta}{1+\frac{1}{2}} = \frac{2}{3}g\sin\theta$$

So, acceleration of solid sphere is more. It implies that solid sphere reaches the bottom first.

79 The speed of a homogeneous solid sphere after rolling down an inclined plane of vertical height h from rest without sliding is **[CBSE AIPMT 1992]**

(a) $\sqrt{\frac{10}{7}gh}$ (b) $\sqrt{gh}$
(c) $\sqrt{\frac{6}{5}gh}$ (d) $\sqrt{\frac{4}{3}gh}$

Ans. *(a)*

When solid sphere rolls on inclined plane, then it has both rotational as well as translational kinetic energy

Total kinetic energy

$$K = K_{rot} + K_{trans} = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2$$

For sphere, moment of inertia about its diameter

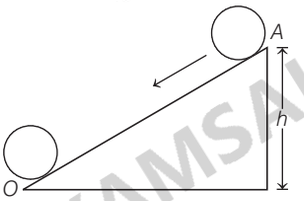
$$I = \frac{2}{5}mr^2$$

$$\therefore \quad K = \frac{1}{2}\left(\frac{2}{5}mr^2\right)\omega^2 + \frac{1}{2}mv^2$$

$$= \frac{1}{5}mr^2\omega^2 + \frac{1}{2}mv^2$$

$$= \frac{1}{5}mv^2 + \frac{1}{2}mv^2 \quad (\text{as } v = r\omega)$$

$$= \frac{7}{10}mv^2$$



On reaching sphere at O, it has only kinetic energy

$$\therefore \quad \text{PE} = \text{Total KE}$$

$$mgh = \frac{7}{10}mv^2$$

$$\Rightarrow \quad v = \sqrt{\frac{10gh}{7}}$$

80 If a sphere is rolling, the ratio of the translational energy to total kinetic energy is given by **[CBSE AIPMT 1991]**

(a) 7 : 10 (b) 2 : 5 (c) 10 : 7 (d) 5 : 7

Ans. *(d)*

When sphere rolls, then it has both translational and rotational kinetic energy

$$\therefore \quad K = K_{rot} + K_{trans}$$

$$= \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2$$

$\because$ Moment of inertia of the sphere about its diameter is

$$I = \frac{2}{5}mr^2$$

$$\therefore \quad K = \frac{1}{2}\left(\frac{2}{5}mr^2\right)\omega^2 + \frac{1}{2}mv^2$$

(as $v = r\omega$)

$$\therefore \quad K = \frac{1}{5}mv^2 + \frac{1}{2}mv^2 = \frac{7}{10}mv^2$$

$$\therefore \quad \frac{K_t}{K} = \frac{\frac{1}{2}mv^2}{\frac{7}{10}mv^2} = \frac{5}{7}$$

81 The moment of inertia of a body about a given axis is 1.2 kg-m^2. Initially, the body is at rest. In order to produce a rotational kinetic energy of 1500 J, an angular acceleration of 25 rad / s^2 must be applied about that axis for a duration of **[CBSE AIPMT 1990]**

(a) 4 s (b) 2 s
(c) 8 s (d) 10 s

Ans. *(b)*

Given,

Moment of inertia, $I = 1.2$ kg-m^2

Rotational kinetic energy, $K_r = 1500$ J

Angular acceleration

$$\alpha = 25 \text{ rad/s}^2, \omega_0 = 0, t = ?$$

Kinetic energy of rotation is given by

$$K_{rot} = \frac{1}{2}I\omega^2$$

$$\therefore \quad \omega = \sqrt{\frac{2K_r}{I}} = \sqrt{\frac{2\times 1500}{1.2}}$$

$$= 50 \text{ rad/s}$$

Now, from equation of rotational motion

$$\omega = \omega_0 + \alpha t$$

$$t = \frac{\omega - \omega_0}{\alpha}$$

$$= \frac{50-0}{25} = 2 \text{ s}$$

82 Moment of inertia of a uniform circular disc about a diameter is I. Its moment of inertia about an axis perpendicular to its plane and passing through a point on its rim will be **[CBSE AIPMT 1990]**

(a) $5I$ (b) $3I$
(c) $6I$ (d) $4I$

Ans. *(c)*

Problem Solving Strategy

For this type of problem, always apply parallel and perpendicular axes theorem of moment of inertia.

Moment of inertia of uniform circular disc about its diameter $= I$

According to theorem of perpendicular axes,

Moment of inertia of disc about its axis $= 2I$

Applying theorem of parallel axes,

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Moment of inertia of disc about the given axis

$= 2I + mr^2$

$= 2I + 4I$

$\left(\text{as} 2I = \frac{1}{2} mr^2 \therefore mr^2 = 4I\right)$

$\therefore \quad = 6I$

83 A flywheel rotating about a fixed axis has a kinetic energy of 360 J when its angular speed is 30 rad/s. The moment of inertia of the wheel about the axis of rotation is **[CBSE AIPMT 1990]**

(a) 0.6 kg -m^2 (b) 0.15 kg -m^2

(c) 0.8 kg -m^2 (d) 0.75 kg -m^2

Ans. *(c)*

A flywheel is a large heavy wheel with a long cylindrical axle supported on ball bearings. Its centre of mass lies on its axis of rotation, so that it remains at rest in any position. Rotational kinetic energy of flywheel is given by

$$K_{\text{rot}} = \frac{1}{2} I\omega^2$$

where, I = moment of inertia of the wheel about the axis of rotation

ω = angular velocity of flywheel

Given, Rotational kinetic energy $K_r = 360$ J

Angular velocity $\omega = 30$ rad/s

$$\therefore \quad I = \frac{2K_r}{\omega^2} = \frac{2 \times 360}{(30)^2}$$

$$= 0.8 \text{ kg-m}^2$$

84 At any instant, a rolling body may be considered to be in pure rotation about an axis through the point of contact. This axis is translating forward with speed **[CBSE AIPMT 1989]**

(a) equal to centre of mass

(b) zero

(c) twice of centre of mass

(d) None of the above

Ans. *(a)*

Since, in this case, instantaneous axis of rotation is always below the centre of mass. This is possible only when point of contact moves with a velocity equal to centre of mass.

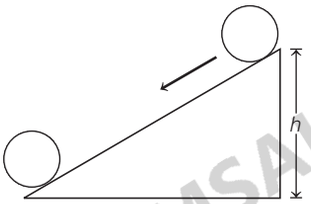
85 A solid cylinder of mass M and radius R rolls down an inclined plane of height h without slipping. The speed of its centre of mass when it reaches the bottom is **[CBSE AIPMT 1989]**

(a) $\sqrt{2gh}$ (b) $\sqrt{\frac{4gh}{3}}$

(c) $\sqrt{\frac{3gh}{4}}$ (d) $\sqrt{\frac{4g}{h}}$

Ans. *(b)*

When solid cylinder rolls down on an inclined plane, then it has both rotational and translational kinetic energy



Total kinetic energy $K = K_{\text{rot}} + K_{\text{trans}}$

or $K = \frac{1}{2} I\omega^2 + \frac{1}{2} mv^2$

where, I = moment of inertia of solid cylinderabout its axis

$$= \frac{1}{2} mr^2$$

$$\therefore \quad K = \frac{1}{2}\left(\frac{1}{2} mr^2\right)\omega^2 + \frac{1}{2} mv^2$$

$$= \frac{1}{4} mv^2 + \frac{1}{2} mv^2 \qquad (\text{as } v = r\omega)$$

$$= \frac{3}{4} mv^2$$

Now, gain in KE = loss in PE

$$\therefore \quad \frac{3}{4} mv^2 = mgh$$

$$\Rightarrow \quad v = \sqrt{\left(\frac{4}{3} gh\right)}$$

86 A ring of mass m and radius r rotates about an axis passing through its centre and perpendicular to its plane with angular velocity ω. Its kinetic energy is **[CBSE AIPMT 1988]**

(a) $\frac{1}{2} mr^2\omega^2$ (b) $mr\omega^2$

(c) $mr^2\omega^2$ (d) $\frac{1}{3} mr^2\omega^2$

Ans. *(a)*

Kinetic energy of rotation of a body is the energy possessed by the body on account of its rotation about a given axis. If I is the moment of inertia of the body about the given axis of rotation, ω is angular velocity of the body, then kinetic energy of rotation

$$K_{\text{rot}} = \frac{1}{2} I\omega^2$$

Moment of inertia of the ring about an axis perpendicular to the plane of the ring and passing through its centre is

$$I = mr^2$$

So, $$K_{\text{rot}} = \frac{1}{2} mr^2\omega^2$$

87 A solid homogeneous sphere of mass M and radius R is moving on a rough horizontal surface, partly rolling and partly sliding. During this kind of motion of the sphere **[CBSE AIPMT 1988]**

(a) total kinetic energy is conserved

(b) he angular momentum of the sphere about the point of contact with the plane is conserved

(c) only the rotational kinetic energy about the centre of mass is conserved

(d) angular momentum about the centre of mass is conserved

Ans. *(b)*

Angular momentum about the point of contact, for solid homogeneous sphere of mass M and radius R is conservd.

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07
Gravitation

TOPIC 1
Kepler's Law and Universal Law of Gravitation

01 The time period of a geo-stationary satellite is 24 h, at a height $6R_E$ (R_E is the radius of earth) from surface of earth. The time period of another satellite whose height is $2.5\,R_E$ from surface will be

[NEET (Odisha) 2019]

(a) $6\sqrt{2}$ h (b) $12\sqrt{2}$ h (c) $\frac{24}{2.5}$ h (d) $\frac{12}{2.5}$ h

Ans. *(a)*

From Kepler's third law, the time period of revolution of satellite around earth is

$$T^2 \propto r^3 \quad \text{or} \quad T \propto r^{3/2} \qquad ...(i)$$

where, r is the radius of satellite's orbit.

Here, $r_1 = 6R_E + R_E, T_1 = 24$ h

$r_2 = 2.5R_E + R_E, T_2 = ?$

where R_E = radius of earth

So, from Eq. (i), we get

$$\frac{T_1}{T_2} = \left(\frac{r_1}{r_2}\right)^{3/2}$$

$$\frac{24}{T_2} = \left(\frac{6R_E + R_E}{2.5R_E + R_E}\right)^{3/2} = \left(\frac{7}{3.5}\right)^{3/2}$$

$$\Rightarrow \quad T_2 = \frac{24}{(2)^{3/2}} = \frac{24}{2\sqrt{2}} = \frac{12}{\sqrt{2}} = 6\sqrt{2}\text{ h}$$

02 The kinetic energies of a planet in an elliptical orbit about the Sun, at positions A, B and C are K_A, K_B and K_C, respectively. AC is the major axis and SB is perpendicular to AC at the position of the Sun S as shown in the figure. Then

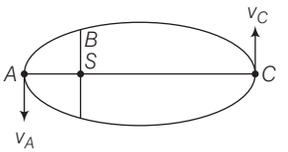
[NEET 2018]

(a) $K_B < K_A < K_C$ (b) $K_A > K_B > K_C$

(c) $K_A < K_B < K_C$ (d) $K_B > K_A > K_C$

Ans. *(b)*

According to the question,



The figure above shows an ellipse traced by a planet around the Sun, S. The closed point A is known as perihelion (perigee) and the farthest point C is known as aphelion (apogee).

Since, as per the result the Kepler's second law of area, that the planet will move slowly (v_{min}) only when it is farthest from the Sun and more rapidly (v_{max}) when it is nearest to the Sun.

Thus, $v_A = v_{max}, v_C = v_{min}$

Therefore, we can write

$$v_A > v_B > v_C \qquad ...(i)$$

Kinetic energy of the planet at any point is given as, $K = \frac{1}{2}mv^2$

Thus, at A, $K_A = \frac{1}{2}mv_A^2$

At B, $K_B = \frac{1}{2}mv_B^2$

At C, $K_C = \frac{1}{2}mv_C^2$

From Eq. (i), we can write

$$K_A > K_B > K_C$$

03 Kepler's third law states that square of period of revolution (T) of a planet around the sun, is proportional to third power of average distance r between the sun and planet i.e. $T^2 = Kr^3$, here K is constant.

If the masses of the sun and planet are M and m respectively, then as per Newton's law of gravitation force of attraction between them is

[CBSE AIPMT 2015]

$F = \frac{GMm}{r^2}$, here G is gravitational constant. The relation between G and K is described as

(a) $GK = 4\pi^2$ (b) $GMK = 4\pi^2$

(c) $K = G$ (d) $K = \frac{l}{G}$

Ans. *(b)*

The gravitational force of attraction between the planet and sun provide the centripetal force

i.e. $$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$\Rightarrow \quad v = \sqrt{\frac{GM}{r}}$$

The time period of planet will be

$$T = \frac{2\pi r}{v}$$

$$\Rightarrow T^2 = \frac{4\pi^2 r^2}{\frac{GM}{r}} = \frac{4\pi^2 r^3}{GM} \qquad ...(i)$$

Also from Kepler's third law

$$T^2 = Kr^3 \qquad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\frac{4\pi^2 r^3}{GM} = Kr^3 \Rightarrow GMK = 4\pi^2$$

04 Two spherical bodies of masses M and $5M$ and radii R and $2R$ are released in free space with initial separation between their centres equal to $12R$. If they attract each other due to gravitational force only, then the distance covered by the smaller body before collision is

[CBSE AIPMT 2015]

(a) 2.5 R (b) 4.5 R

(c) 7.5 R (d) 1.5 R

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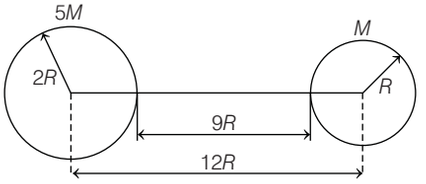
Ans. *(c)*

Suppose, the smaller body cover a distance x before collision, then



$$Mx = 5M(9R - x)$$

or $$x = 45R - 5x$$

or $$x = \frac{45R}{6} = 7.5R$$

05 A geostationary satellite is orbiting the earth at a height of $5R$ above that surface of the earth, R being the radius of the earth. The time period of another satellite in hour at a height of $2R$ from the surface of the earth is **[CBSE AIPMT 2012]**

(a) 5 (b) 10
(c) $6\sqrt{2}$ (d) $6/\sqrt{2}$

Ans. *(c)*

From Kepler's third law

$$T^2 \propto r^3$$

[where, T = time period of satellite
r = radius of elliptical orbit (semi major axis)]

Hence, $T_1^2 \propto r_1^3$ and $T_2^2 \propto r_2^3$

So, $$\frac{T_2^2}{T_1^2} = \frac{r_2^3}{r_1^3} = \frac{(3R)^3}{(6R)^3} \text{ or } \frac{T_2^2}{T_1^2} = \frac{1}{8}$$

$$T_2^2 = \frac{1}{8}T_1^2 \Rightarrow T_2 = \frac{24}{2\sqrt{2}} = 6\sqrt{2}\ \text{h}$$

06 A planet moving along an elliptical orbit is closest to the sun at a distance r_1 and farthest away at a distance of r_2. If v_1 and v_2 are the linear velocities at these points respectively, then the ratio $\frac{v_1}{v_2}$ is **[CBSE AIPMT 2011]**

(a) r_2 / r_1 (b) $(r_2 / r_1)^2$
(c) r_1 / r_2 (d) $(r_1 / r_2)^2$

Ans. *(a)*

Concept Apply conservation of angular momentum.

From the law of conservation of angular momentum, $L_1 = L_2$

So, $mr_1v_1 = mr_2v_2$

[where, m = mass the of planet
r = radius of orbit
v = velocity of the planet]

$$r_1v_1 = r_2v_2 \Rightarrow \frac{v_1}{v_2} = \frac{r_2}{r_1}$$

07 Two satellites of the earth, S_1 and S_2 are moving in the same orbit. The mass of S_1 is four times the mass of S_2. Which one of the following statements is true? **[CBSE AIPMT 2007]**

(a) The time period of S_1 is four times that of S_2
(b) The potential energies of the earth and satellite in the two cases are equal
(c) S_1 and S_2 are moving with the same speed
(d) The kinetic energies of the two satellites are equal

Ans. *(c)*

When two satellites of the earth are moving in same orbit, then time period of both are equal.

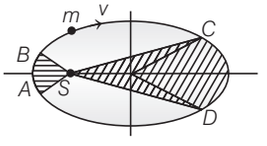
From Kepler's third law $T^2 \propto r^3$

Time period is independent of mass, hence their time periods will be equal.

The potential energy and kinetic energy are mass dependent, hence the potential energy and kinetic energy of satellites are not equal.

But, if they are orbiting in a same orbit, then they have equal orbital speed.

08 The figure shows elliptical orbit of a planet m about the sun S. The shaded area SCD is twice the shaded area SAB. If t_1 is the time for the planet to move from C to D and t_2 is the time to move from A to B, then **[CBSE AIPMT 2009]**



(a) $t_1 > t_2$ (b) $t_1 = 4\,t_2$
(c) $t_1 = 2\,t_2$ (d) $t_1 = t_2$

Ans. *(c)*

Concept Apply Kepler's second law.

The line joining the sun to the planet sweeps out equal areas in equal time interval i.e. areal velocity is constant.

$$\frac{dA}{dt} = \text{constant} \text{ or } \frac{A_1}{t_1} = \frac{A_2}{t_2}$$

where, A_1 = area under SCD
A_2 = area under ABS

$$\Rightarrow t_1 = \frac{A_1}{A_2}t_2$$

Given, $A_1 = 2A_2$

$\therefore$ $t_1 = 2\,t_2$

09 Two spheres of masses m and M are situated in air and the gravitational force between them is F. The space around the masses is now filled with a liquid of specific gravity 3. The gravitational force will now be **[CBSE AIPMT 2003]**

(a) $\frac{F}{3}$ (b) $\frac{F}{9}$ (c) $3F$ (d) F

Ans. *(d)*

According to Newton's law of gravitation, the force between two spheres is given by,

$$F = \frac{GMm}{r^2}$$

From the relation, we can say the gravitational force does not depend on the medium between two spheres hence, it remains same, i.e. F.

10 The period of revolution of the planet A round the sun is 8 times that of B. The distance of A from the sun is how many times greater than that of B from the sun? **[CBSE AIPMT 1997]**

(a) 5 (b) 4 (c) 3 (d) 2

Ans. *(b)*

According to Kepler's third law

$$T^2 \propto r^3$$

where, T = Time period of revolution
r = Semi major axis

$\therefore$ $$\frac{T_A^2}{T_B^2} = \frac{r_A^3}{r_B^3}$$

$\therefore$ $$\frac{r_A}{r_B} = \left(\frac{T_A}{T_B}\right)^{2/3} = (8)^{2/3} = 2^{3\times\frac{2}{3}} = 4$$

or $r_A = 4r_B$

11 A satellite A of mass m is at a distance r from the surface of the earth. Another satellite B of mass $2m$ is at a distance of $2r$ from the earth's surface. Their time periods are in the ratio of **[CBSE AIPMT 1993]**

(a) 1 : 2 (b) 1 : 16
(c) 1 : 32 (d) $1 : 2\sqrt{2}$

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Ans. *(d)*

According to Kepler's third law, the square of the time period of revolution of a planet around the sun is directly proportional to the cube of semi major-axis of its elliptical orbit i.e.

$$T^2 \propto r^3$$

where, T = time taken by the planet to go once around the sun.

r = semi-major axis of the elliptical orbit

$$\therefore \quad \frac{T_1^2}{T_2^2} = \frac{(r)^3}{(2r)^3} = \frac{1}{8} \Rightarrow \frac{T_1}{T_2} = \frac{1}{2\sqrt{2}}$$

12 If the gravitational force between two objects were proportional to $\frac{1}{R}$ (and not as $\frac{1}{R^2}$), where R is separation between them, then a particle in circular orbit under such a force would have its orbital speed v proportional to **[CBSE AIPMT 1989]**

(a) $\frac{1}{R^2}$ (b) R^0

(c) R (d) $\frac{1}{R}$

Ans. *(b)*

According to question, gravitational force between two objects

$$F = \frac{k}{R}$$

In equilibrium, the gravitational force provides the required centripetal force to the particle

$$\therefore \quad \frac{mv^2}{R} = \frac{k}{R}$$

Hence, $v \propto R^0$

13 The distances of two planets from the sun are 10^{13} and 10^{12} m respectively. The ratio of time periods of these two planets is **[CBSE AIPMT 1988]**

(a) $\frac{1}{\sqrt{10}}$ (b) 100

(c) $10\sqrt{10}$ (d) $\sqrt{10}$

Ans. *(c)*

According to Kepler's third law (or law of periods) the square of the time taken to complete the orbit (time period T) is proportional to the cube of the semi-major axis (r) of the elliptical orbit

i.e. $T^2 \propto r^3$

Here, $r_1 = 10^{13}$ m, $r_2 = 10^{12}$ m

$$\therefore \quad \frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3} = \frac{(10^{13})^3}{(10^{12})^3}$$

or $$\frac{T_1^2}{T_2^2} = \frac{10^{39}}{10^{36}} = 10^3$$

or $$\frac{T_1}{T_2} = 10\sqrt{10}$$

14 The largest and the shortest distance of the earth from the sun are r_1 and r_2. Its distance from the sun when it is perpendicular to the major axis of the orbit drawn from the sun **[CBSE AIPMT 1988]**

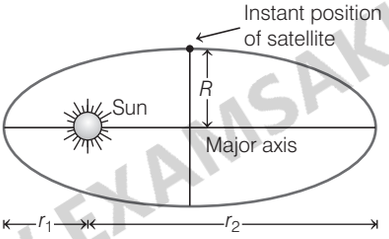
(a) $\frac{r_1 + r_2}{4}$ (b) $\frac{r_1 + r_2}{r_1 - r_2}$

(c) $\frac{2r_1r_2}{r_1 + r_2}$ (d) $\frac{r_1 + r_2}{3}$

Ans. *(c)*

From the property of ellipse,

$$\frac{2}{R} = \frac{1}{r_1} + \frac{1}{r_2}$$



or $$\frac{2}{R} = \frac{r_1 + r_2}{r_1 r_2} \Rightarrow R = \frac{2r_1r_2}{r_1 + r_2}$$

TOPIC 2

Acceleration Due to Gravity and Gravitational PE

15 What is the depth at which the value of acceleration due to gravity becomes $1/n$ times the value that the surface of earth? (Radius of earth $= R$) **[NEET (Oct.) 2020]**

(a) R/n^2 (b) $R(n-1)/n$

(c) $Rn/(n-1)$ (d) R/n

Ans. *(b)*

Radius of earth $= R$

Let at depth d, gravitational acceleration becomes $\frac{g}{n}$.

i.e., $$g_d = \frac{g}{n} \Rightarrow g\left(1 - \frac{d}{R}\right) = \frac{g}{n}$$

$$\Rightarrow \quad 1 - \frac{d}{R} = \frac{1}{n} \Rightarrow 1 - \frac{1}{n} = \frac{d}{R}$$

$$\Rightarrow \quad \frac{n-1}{n} = \frac{d}{R} \Rightarrow d = \left(\frac{n-1}{n}\right)R$$

16 A body weighs 72 N on the surface of the earth. What is the gravitational force on it, at a height equal to half of radius of the earth? **[NEET (Sep.) 2020]**

(a) 32 N (b) 30 N (c) 24 N (d) 48 N

Ans. *(a)*

Given, $w = mg = 72$ N (on the surface of earth).

At height equal to half of radius of the earth, $\left(\text{i.e.}\, h = \frac{R}{2}\right)$

Acceleration due to gravity,

$$g' = g\left(\frac{R}{R+h}\right)^2$$

$$= g\left(\frac{R}{R + R/2}\right)^2 = g\left(\frac{4R^2}{9R^2}\right)$$

$$\Rightarrow \quad g' = \frac{4}{9}g$$

$$\Rightarrow \quad mg' = \frac{4}{9}mg = \frac{4}{9} \times 72 = 32 \text{ N}$$

$$w' = 32 \text{ N}$$

Hence, correct option is (a).

17 Assuming that the gravitational potential energy of an object at infinity is zero, the change in potential energy (final – initial) of an object of mass m, when taken to a height h from the surface of earth (of radius R) is given by, **[NEET (Odisha) 2019]**

(a) $-\frac{GMm}{R+h}$ (b) $\frac{GMmh}{R(R+h)}$

(c) mgh (d) $\frac{GMm}{R+h}$

Ans. *(b)*

The gravitational potential energy of an object placed at earth's surface is

$$U_1 = -\frac{GMm}{R} \qquad \ldots(i)$$

where, G = gravitational constant,

M = Mass of earth, m = mass of object and R = radius of the earth

The negative sign in the above relation indicates that it is the work done in bringing the object from infinity to a distance R.

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The gravitational potential energy of object at a height h above the surface of earth is

$$U_2 = -\frac{GMm}{(R+h)} \quad ...(ii)$$

So, the change in potential energy is

$$\Delta U = U_2 - U_1 = -\frac{GMm}{R+h} - \left(-\frac{GMm}{R}\right)$$

[From Eq. (i) and (ii)]

$$= -GMm\left[\frac{1}{(R+h)} - \frac{1}{R}\right]$$

$$= -GMm\left(-\frac{h}{R(R+h)}\right)$$

$$= \frac{GMmh}{R(R+h)}$$

18 A body weighs 200 N on the surface of the earth. How much will it weigh half way down to the centre of the earth ?

[NEET (National) 2019]

(a) 200 N (b) 250 N (c) 100 N (d) 150 N

Ans. ***(c)***

Given, weight of the body, $w = 200$ N

As we know,

$w = mg$, where m is the mass of the body and g ($\approx 10\ m/s^2$) is acceleration due to gravity of the body at the surface of the earth.

Since, mass m remains constant irrespective of the position of the body on the earth. However, g is not constant and its value at a depth d below the earth's surface is given as

$$g' = g\left(1 - \frac{d}{R}\right) \quad ...(i)$$

where, R is the radius of the earth.

Multiplying m on the both sides of Eq. (i), we get

$$mg' = mg\left(1 - \frac{d}{R}\right)$$

Thus, the weight of the body at half way down $\left(\text{i.e.}\, d = \frac{R}{2}\right)$ to the centre of the earth is

$$mg' = 200 \times \left(1 - \frac{R/2}{R}\right)$$

$$= 200\left(1 - \frac{1}{2}\right) = 200 \times \frac{1}{2} = 100$$

$\therefore$ The body will weigh 100 N half way down to the centre of the earth.

19 The work done to raise a mass m from the surface of the earth to a height h, which is equal to the radius of the earth, is

[NEET (National) 2019]

(a) $2mgR$

(b) $\frac{1}{2}mgR$

(c) $\frac{3}{2}mgR$

(d) mgR

Ans. ***(b)***

Key Idea Amount of work done in moving the given body from one point to another against the gravitational force is equal to the change in potential energy of the body.

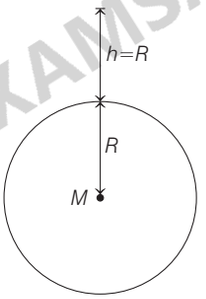
As we know, the potential energy of body of mass m of the surface of earth is

$$U_1 = -\frac{GMm}{R} \quad ...(i)$$

where, G = gravitational constant,

M = mass of earth and R = radius of earth.

When the mass is raised to a height h from the surface of the earth, then the potential energy of the body becomes



$$U_2 = -\frac{GMm}{(R+h)}$$

Here, $h = R$ (given)

$$\Rightarrow \quad U_2 = -\frac{GMm}{2R} \quad ...(ii)$$

Thus, the change in potential energy, $\Delta U = U_2 - U_1$

Substituting the values from Eqs. (i) and (ii), we get

$$\Delta U = -\frac{GMm}{2R} + \frac{GMm}{R}$$

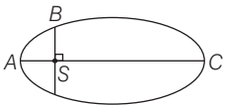
$$= \frac{GMm}{2R} = \frac{gR^2 m}{2R} \qquad \left[\because g = \frac{GM}{R^2}\right]$$

$$= \frac{mgR}{2}$$

Thus, the work done in raising the mass to a height R is equals to $\frac{mgR}{2}$.

20 If the mass of the Sun were ten times smaller and the universal gravitational constant were ten times larger in magnitude, which of the following is not correct?

[NEET 2018]



(a) Time period of a simple pendulum on the Earth would decrease

(b) Walking on the ground would become more difficult

(c) Raindrops will fall faster

(d) 'g' on the Earth will not change

Ans. ***(d)***

Let the original mass of Sun was M_s and gravitational constant G'.

According to the question,

New mass of Sun, $M_s' = \frac{M_s}{10}$

New gravitational constant, $G' = 10G$

As, the acceleration due to gravity is given as

$$g = \frac{GM_E}{R^2} \quad ...(i)$$

where, M_E is the mass of Earth and R is the radius of the Earth.

Now, new acceleration due to gravity,

$$g' = \frac{G'M_e}{R^2}$$

$$= \frac{10\,M_e G}{R^2} \quad ...(ii)$$

$\therefore \quad g' = 10\,g$ [from Eqs. (i) and (ii)]

This means the acceleration due to gravity has been increased. Hence, force of gravity acting on a body placed on or surface of the Earth increases.

Due to this, rain drops will fall faster, walking on ground would become more difficult.

As, time period of the simple pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}} \quad \text{Or } T \propto \frac{1}{\sqrt{g}}$$

Thus, time period of the pendulum also decreases with the increase in g.

21 The acceleration due to gravity at a height 1 km above the earth is the same as at a depth d below the surface of earth. Then **[NEET 2017]**

(a) $d = \frac{1}{2}$ km (b) $d = 1$ km

(c) $d = \frac{3}{2}$ km (d) $d = 2$ km

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Ans. *(d)*

Thinking Process g_h = Acceleration due to gravity at height h above earth's surface

$$= g\left(\frac{R}{R+h}\right)^2 = g\left(1-\frac{2h}{R}\right)$$

g_d = Acceleration at depth d below earth's surface

$$= g\left(1-\frac{d}{R}\right)$$

Given, when $h = 1$ km, $g_d = g_h$

or $g\left(1-\frac{d}{R}\right) = g\left(1-\frac{2h}{R}\right)$

$\Rightarrow \quad d = 2h$ or $d = 2$ km

22 Two astronauts are floating in gravitational free space after having lost contact with their spaceship. The two will **[NEET 2017]**

(a) keep floating at the same distance between them
(b) move towards each other
(c) move away from each other
(d) will become stationary

Ans. *(b)*

In the space, there is no external gravity. Due to masses of the astronauts, there will be small gravitational attractive force between them. Thus, these astronauts will move towards each other.

23 At what height from the surface of earth the gravitation potential and the value of g are -5.4×10^7 J kg^{-2} and 6.0 ms^{-2} respectively? Take, the radius of earth as 6400 km. **[NEET 2016]**

(a) 1600 km (b) 1400 km
(c) 2000 km (d) 2600 km

Ans. *(d)*

Gravitational potential at some height h from the surface of the earth is given by

$$V = -\frac{GM}{R+h} \qquad ...(i)$$

And acceleration due to gravity at some height h from the earth surface can be given as

$$g' = \frac{GM}{(R+h)^2} \qquad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\frac{|V|}{g'} = \frac{GM}{(R+h)} \times \frac{(R+h)^2}{GM}$$

$$\Rightarrow \quad \frac{|V|}{g'} = R+h \qquad (iii)$$

$\because\ V = -5.4\times10^7$ J kg^{-2} and $g' = 6.0$ ms^{-2}

Radius of earth, $R = 6400$ km.

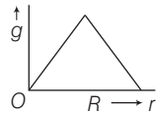
Substitute these values in Eq. (iii), we get

$$\frac{5.4\times10^7}{6.0} = R+h \Rightarrow 9\times10^6 = R+h$$

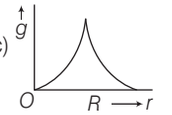
$$\Rightarrow \quad h = (9-6.4)\times10^6 = 2.6\times10^6 \text{ m}$$

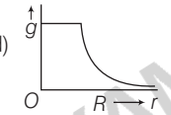
$$\Rightarrow \quad h = 2600 \text{ km}$$

24 Starting from the centre of the earth having radius R, the variation of g (acceleration due to gravity) is shown by **[NEET 2016]**

(a) 

(b)

(c) 

(d) 

Ans. *(b)*

Acceleration due to gravity at a depth d below the surface of the earth is given by

$$g_{\text{depth}} = g_{\text{surface}}\left(1-\frac{d}{R}\right)$$

Also, for a point at height h above surface,

$$g_{\text{height}} = g_{\text{surface}}\left[\frac{R^2}{(R+h)^2}\right]$$

Therefore, we can say that value of g increases from centre of maximum at the surface and then decreases as depicted in graph (b).

25 Infinite number of bodies, each of mass 2 kg are situated on X-axis at distances 1m, 2 m, 4 m and 8 m, respectively from the origin. The resulting gravitational potential due to this system at the origin will be **[NEET 2013]**

(a) $-G$ (b) $-\frac{8}{3}G$
(c) $-\frac{4}{3}G$ (d) $-4G$

Ans. *(d)*

The resulting gravitational potential,

$$V = -2G\left[\frac{1}{1}+\frac{1}{2}+\frac{1}{4}+\frac{1}{8}+\ldots\right]$$

$$\Rightarrow \quad V = -2G\left[1+\frac{1}{2}+\frac{1}{2^2}+\frac{1}{2^3}\ldots\right]$$

$$\Rightarrow \quad V = -2G\left(1+\frac{1}{2}\right)^{-1}$$

$$\Rightarrow \quad V = -\frac{2G}{\left(1-\frac{1}{2}\right)} = -\frac{2G}{\left(\frac{1}{2}\right)} = -4G$$

26 A body of mass m taken from the earth's surface to the height equal to twice the radius (R) of the earth. The change in potential energy of body will be **[NEET 2013]**

(a) $mg2R$ (b) $\frac{2}{3}mgR$
(c) $3mgR$ (d) $\frac{1}{3}mgR$

Ans. *(b)*

Change in potential energy

So, $\quad \Delta U = -\frac{GMm}{R+2R} - \left(-\frac{GMm}{R}\right)$

where, $U_{\text{Final}} = \frac{GMm}{R+2R}$

$$U_{\text{initial}} = \frac{-GMm}{R}$$

$$\therefore\ \Delta U = -\frac{GMm}{3R} + \frac{GMm}{R}$$

$$= \frac{2GMm}{3R} = \frac{2}{3}mgR \qquad \left[\because g = \frac{GM}{R^2}\right]$$

27 The height at which the weight of a body becomes 1/16th, its weight on the surface of the earth (radius R), is **[CBSE AIPMT 2012]**

(a) $5R$ (b) $15R$
(c) $3R$ (d) $4R$

Ans. *(c)*

According to the question,

$$\frac{GMm}{(R+h)^2} = \frac{1}{16}\frac{GMm}{R^2}$$

where, m = mass of the body

and $\frac{GM}{R^2}$ = gravitational acceleration

$$\frac{1}{(R+h)^2} = \frac{1}{16R^2} \text{ or } \frac{R}{R+h} = \frac{1}{4}$$

or $\frac{R+h}{R} = 4$

$$h = 3R$$

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28 A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It **[CBSE AIPMT 2012]**

(a) will become rigid showing no movement
(b) will stay in any position
(c) will stay in North-South direction only
(d) will stay in East-West direction only

Ans. *(c)*

It will stay in North-South direction only at geomagnetic North and South poles.

29 A spherical planet has a mass M_p and diameter D_p. A particle of mass m falling freely near the surface of this planet will experience an acceleration due to gravity, equal to **[CBSE AIPMT 2012]**

(a) $4GM_p/D_p^2$ (b) GM_pm/D_p^2
(c) GM_p/D_p^2 (d) $4GM_pm/D_p^2$

Ans. *(a)*

Concept Apply Newton's gravitation law.

According to Newton's law of gravitation force,

$$F=\frac{GMm}{R^2}$$

Force on planet of mass M_P and body of mass m is given by

$$F=\frac{GM_Pm}{(D_P/2)^2}$$

[where, D_P = diameter of planet and R_P = radius of planet $=\frac{D_P}{2}$]

$$F=\frac{4GM_Pm}{D_P^2}$$

As we know that, $F=ma$

So, acceleration due to gravity

$$a=\frac{F}{m}=\frac{4GM_P}{D_P^2}$$

30 A body projected vertically from the earth reaches a height equal to earth's radius before returning to the earth. The power exerted by the gravitational force is greatest **[CBSE AIPMT 2011]**

(a) at the instant just before the body hits the earth
(b) it remains constant all through
(c) at the instant just after the body is projected
(d) at the highest position of the body

Ans. *(a)*

We know that, Power, $P=\mathbf{F}\cdot\mathbf{V}=FV\cos\theta$

So, just before hitting, θ is zero, power will be maximum.

31 A particle of mass M is situated at the centre of a spherical shell of same mass and radius a. The gravitational potential at a point situated at $a/2$ distance from the centre, will be **[CBSE AIPMT 2010]**

(a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$
(c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$

Ans. *(a)*

Gravitational potential at point $a/2$ distance from centre is given by,

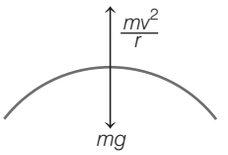
$$V=-\frac{GM}{a}-\frac{GM}{a/2}=-\frac{3GM}{a}$$

32 A roller coaster is designed such that riders experience "weightlessness" as they go round the top of a hill whose radius of curvature is 20 m. The speed of the car at the top of the hill is between **[CBSE AIPMT 2008]**

(a) 14 m/s and 15 m/s
(b) 15 m/s and 16 m/s
(c) 16 m/s and 17 m/s
(d) 13 m/s and 14 m/s

Ans. *(a)*

The appearance of weightlessness occurs in space when the gravitational attraction of the earth on a body in space is equal to the centripetal force.



$$\therefore\quad \frac{mv^2}{r}=mg$$

or $$v=\sqrt{rg}=\sqrt{20\times10}=14.14\text{ m/s}$$

33 Imagine a new planet having the same density as that of the earth but it is 3 times bigger than the earth in size. If the acceleration due to gravity on the surface of the earth is g and that on the surface of the new planet is g', then **[CBSE AIPMT 2005]**

(a) $g'=3g$ (b) $g'=\frac{g}{9}$
(c) $g'=9g$ (d) $g'=27g$

Ans. *(a)*

The acceleration due to gravity on the new planet can be found using the relation

$$g=\frac{GM}{R^2} \qquad ...(i)$$

but $M=\frac{4}{3}\pi R^3\rho$, ρ being density.

Thus, Eq. (i) becomes

$$g=\frac{G\times\frac{4}{3}\pi R^3\rho}{R^2}=G\times\frac{4}{3}\pi R\rho$$

$$\Rightarrow\quad g\propto R$$

$$\therefore\quad \frac{g'}{g}=\frac{R'}{R}$$

$$\Rightarrow\quad \frac{g'}{g}=\frac{3R}{R}=3\ \Rightarrow\ g'=3g$$

34 The density of newly discovered planet is twice that of the earth. The acceleration due to gravity at the surface of the planet is equal to that at the surface of the earth. If the radius of the earth is R, the radius of the planet would be **[CBSE AIPMT 2004]**

(a) $2R$ (b) $4R$ (c) $\frac{1}{4}R$ (d) $\frac{1}{2}R$

Ans. *(d)*

The acceleration due to gravity on an object of mass m

$$g=\frac{F}{m}$$

but from Newton's law of gravitation

$$F=\frac{GMm}{R^2}$$

where, M is the mass of the earth and R is the radius of the earth.

$$\therefore\quad g=\frac{GMm/R^2}{m}=\frac{GM}{R^2}$$

$$[\because M_p=\frac{4}{3}\pi R_p^3P_p \text{ and } M_e=\frac{4}{3}\pi R_e^3P_e]$$

Given, $\rho_{\text{planet}}=2\rho_{\text{earth}}$

Also, $g_{\text{planet}}=g_{\text{earth}}$

$$\frac{GM_p}{R_p^2}=\frac{GM_e}{R_e^2}$$

As, $$\text{Density}(\rho)=\frac{\text{Mass}(M)}{\text{Volume}(V)}$$

So, $$\frac{G\times\frac{4}{3}\pi R_p^3\rho_p}{R_p^2}=\frac{G\times\frac{4}{3}\pi R_e^3\rho_e}{R_e^2}$$

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or $R_p \rho_p = R_e \rho_e$

or $R_p \times 2\rho_e = R_e \rho_e$

or $R_p = \frac{R_e}{2} = \frac{R}{2}$

35 The acceleration due to gravity on the planet *A* is 9 times the acceleration due to gravity on the planet *B*. A man jumps to a height of 2m on the surface of *A*. What is the height of jump by the same person on the planet *B*?

[CBSE AIPMT 2003]

(a) 6 m (b) $\frac{2}{3}$ m

(c) $\frac{2}{9}$ m (d) 18 m

Ans. *(d)*

It is given that, acceleration due to gravity on planet *A* is 9 times the acceleration due to gravity on planet *B* i.e.

$$g_A = 9g_B \quad ...(i)$$

From third equation of motion,

$$v^2 = 2gh$$

At planet *A*, $h_A = \frac{v^2}{2g_A}$ ...(ii)

At planet *B*, $h_B = \frac{v^2}{2g_B}$ ...(iii)

Dividing Eq. (ii) by Eq. (i), we have

$$\frac{h_A}{h_B} = \frac{g_B}{g_A}$$

From Eq. (i), $g_A = 9g_B$

$$\therefore \quad \frac{h_A}{h_B} = \frac{g_B}{9g_B} = \frac{1}{9}$$

or $h_B = 9h_A = 9 \times 2 = 18\ \text{m}\ (\because h_A = 2\ \text{m})$

36 A body of mass *m* is placed on the earth's surface. It is then taken from the earth's surface to a height $h = 3R$, then the change in gravitational potential energy is

[CBSE AIPMT 2002]

(a) $\frac{mgh}{R}$ (b) $\frac{2}{3}mgR$

(c) $\frac{3}{4}mgR$ (d) $\frac{mgR}{2}$

Ans. *(c)*

Potential energy, $U = -\frac{GMm}{r}$

At the earth's surface, $r = R$

$$\therefore \quad U_e = -\frac{GMm}{R}$$

Now, if a body is taken to height $h = 3R$, then the potential energy is given by

$$U_h = -\frac{GMm}{R+h} \quad (\because r = h + R)$$

$$= -\frac{GMm}{4R}$$

Thus, change in gravitational potential energy,

$$\Delta U = U_h - U_e$$

$$= -\frac{GMm}{4R} - \left(-\frac{GMm}{R}\right)$$

$$= -\frac{GMm}{4R} + \frac{GMm}{R} = \frac{3}{4}\frac{GMm}{R}$$

$$\therefore \quad \Delta U = \frac{3}{4}\frac{gR^2 m}{R} \quad (\because GM = gR^2)$$

$$= \frac{3}{4}mgR$$

37 A body attains a height equal to the radius of the earth. The velocity of the body with which it was projected is **[CBSE AIPMT 2001]**

(a) $\sqrt{\frac{GM}{R}}$ (b) $\sqrt{\frac{2GM}{R}}$

(c) $\sqrt{\frac{5}{4}\frac{GM}{R}}$ (d) $\sqrt{\frac{3GM}{R}}$

Ans. *(a)*

Energy at surface of the earth

= energy at maximum height

or $(K + U)$ at the earth's surface

$= (K + U)$ at maximum height

$$\therefore \quad \frac{1}{2}mu^2 - \frac{GMm}{R} = \frac{1}{2}m \times (0)^2 - \frac{GMm}{R+h}$$

At maximum height it has only potential energy

or $\frac{1}{2}mu^2 = \frac{GMm}{R} - \frac{GMm}{R+R} \quad (\because h = R)$

or $u^2 = \frac{2GM}{R} - \frac{2GM}{2R}$

or $u^2 = \frac{GM}{R} \quad \therefore \quad u = \sqrt{\frac{GM}{R}}$

Alternative

The expression for the speed with which a body should be projected so as to reach a height *h* is

$$u = \sqrt{\frac{2gh}{1 + (h/R)}}$$

Here, $h = R$ (given)

$$u = \sqrt{\frac{2gR}{1 + (R/R)}} = \sqrt{\frac{2 \times \frac{GM}{R^2} \times R}{2}} = \sqrt{\frac{GM}{R}}$$

38 What will be the formula of the mass in terms of g, R and G? (R = radius of the earth)

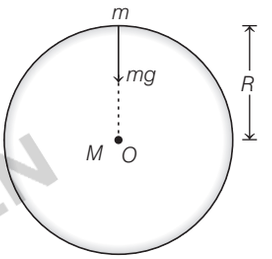
[CBSE AIPMT 1996]

(a) $g^2 \frac{R}{G}$ (b) $G\frac{R^2}{g}$

(c) $G\frac{R}{g}$ (d) $g\frac{R^2}{G}$

Ans. *(d)*

Let *m* be the mass of body, it is placed on spherical body of mass *M*, radius *R* and centre *O*. If acceleration due to gravity is *g* and density of spherical body is uniform such that its mass can be supposed to be concentrated at its centre *O*.



Let *F* be the force of attraction between body of mass *m* and spherical body of mass *M*.

According to Newton's law of gravitation

$$F = \frac{GMm}{R^2}$$

From gravity pull $F = mg$

$$\therefore \quad mg = \frac{GMm}{R^2} \quad \text{or} \quad g = \frac{GM}{R^2}$$

$$\therefore \quad M = \frac{gR^2}{G}$$

39 A seconds pendulum is mounted in a rocket. Its period of oscillation decreases when the rocket

[CBSE AIPMT 1991]

(a) comes down with uniform acceleration

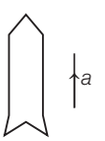
(b) moves round the earth in a geostationary orbit

(c) moves up with a uniform velocity

(d) moves up with uniform acceleration

Ans. *(d)*

When rocket accelerates upward with acceleration *a*, then effective acceleration of rocket is $(g + a)$.



As, $T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\left(\frac{l}{g+a}\right)}$

Hence, period of oscillation of seconds pendulum decreases when the rocket moves up with uniform acceleration.

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40 A planet is moving in an elliptical orbit around the sun. If T, U, E and L stand for its kinetic energy, gravitational potential energy, total energy and magnitude of angular momentum about the centre of force, which of the following is correct? **[CBSE AIPMT 1990]**

(a) T is conserved
(b) U is always positive
(c) E is always negative
(d) L is conserved but direction of vector L changes continuously

Ans. *(c)*

When the planet moves in circular or elliptical orbit, then torque is always acting parallel to displacement or velocity. So, angular momentum is conserved. When the field is attractive, then potential energy is given by

$$U = -\frac{GMm}{R}$$

Negative sign shows that the potential energy is due to attractive gravitational force. Kinetic energy changes as velocity increases when distance is less. Hence, option (c) is correct.

TOPIC 3
Escape Speed and Motion of Satellites

41 The escape velocity from the Earth's surface is v. The escape velocity from the surface of another planet having a radius, four times that of Earth and same mass density is **[NEET 2021]**

(a) v (b) $2v$ (c) $3v$ (d) $4v$

Ans. *(d)*

We know that,

escape velocity from Earth's surface,

$$v_e = \sqrt{\frac{2GM_e}{R_e}}$$

where, G is the gravitational constant,

R_e is the radius of the Earth,

M_e is the mass of the Earth.

Also, $\text{density} = \dfrac{\text{mass}}{\text{volume}}$

$\Rightarrow$ Mass = Density $\times$ Volume

or $M_e = \rho \times V$

or $M_e = \rho \times \dfrac{4}{3}\pi R_e^3 \quad \left(\because V = \dfrac{4}{3}\pi R_e^3\right)$

Substituting the values in the escape velocity expression, we get

$$v_e = \sqrt{\frac{2G\rho \times \frac{4}{3}\pi R_e^3}{R_e}}$$

$$v_e = \sqrt{2G\rho \times \frac{4}{3}\pi R_e^2} \quad \ldots(i)$$

Now, we shall determine the escape velocity for another planet.

Given, radius of another planet is 4 times the radius of the Earth,

$$\Rightarrow \quad v_p = \sqrt{2G\rho \times \frac{4}{3}\pi R_p^2}$$

$$v_p = \sqrt{2G\rho \times \frac{4}{3}\pi (4R_e)^2} \quad (\because R_p = 4R_e)$$

$$v_p = 4\sqrt{2G\rho \times \frac{4}{3}\pi (R_e)^2} \quad \ldots(ii)$$

On dividing Eq. (ii) by Eq. (i), we get

$$\frac{v_p}{v_e} = \frac{4\sqrt{2G\rho \times \frac{4}{3}\pi (R_e)^2}}{\sqrt{2G\rho \times \frac{4}{3}\pi R_e^2}}$$

$$\Rightarrow \quad v_p = 4v_e = 4v$$

42 A particle of mass m is projected with a velocity $v = kv_e$ $(k < 1)$ from the surface of the Earth.

(Here, v_e = escape velocity)

The maximum height above the surface reached by the particle is **[NEET 2021]**

(a) $R\left(\dfrac{k}{1-k}\right)^2$ (b) $R\left(\dfrac{k}{1+k}\right)^2$

(c) $\dfrac{R^2k}{1+k}$ (d) $\dfrac{Rk^2}{1-k^2}$

Ans. *(d)*

Given, the mass of the particle = m

The velocity of the projected particle, $v = kv_e$

Initial energy at the time of projection

$$= \frac{1}{2}mv^2 - \frac{GMm}{R}$$

Final energy at the maximum height h from surface of the Earth

$$= \frac{1}{2}mv^2 - \frac{GMm}{R+h}$$

$$= \frac{1}{2}m(0)^2 - \frac{GMm}{R+h}$$

($\because$ final velocity is zero at height h from the surface of the Earth)

$$= -\frac{GMm}{R+h}$$

Using the law of conservation of energy, initial energy at the time of projection = final energy at the maximum height h from the surface of the Earth

$$\frac{1}{2}mv^2 - \frac{GMm}{R} = -\frac{GMm}{R+h}$$

Substituting the values in the above equation, we get

$$\frac{1}{2}m(kv_e)^2 - \frac{GMm}{R} = -\frac{GMm}{R+h}$$

$$\Rightarrow \frac{1}{2}mk^2\left(2\frac{GM}{R}\right) - \frac{GMm}{R} = -\frac{GMm}{R+h} \quad \left(\because v_e = \sqrt{\frac{2GM}{R}}\right)$$

$$\Rightarrow \quad \frac{k^2}{R} - \frac{1}{R} = -\frac{1}{R+h}$$

$$\Rightarrow \quad \frac{1}{R+h} = \frac{1}{R} - \frac{k^2}{R}$$

$$\Rightarrow \quad \frac{R}{1-k^2} = R + h \;\Rightarrow\; h = \frac{R}{1-k^2} - R$$

$$\Rightarrow \quad h = R\left(\frac{1}{1-k^2} - 1\right)$$

$$\Rightarrow \quad h = R\left(\frac{1-1+k^2}{1-k^2}\right)$$

$$\Rightarrow \quad h = R\left(\frac{k^2}{1-k^2}\right)$$

43 The ratio of escape velocity at earth (v_e) to the escape velocity at a planet (v_p) whose radius and mean density are twice as that of earth is **[NEET 2016]**

(a) $1:2\sqrt{2}$ (b) $1:4$
(c) $1:\sqrt{2}$ (d) $1:2$

Ans. *(a)*

Since, the escape velocity of earth can be given as

$$v_e = \sqrt{2gR} = R\sqrt{\frac{8}{3}\pi G\rho}$$

[ρ = density of earth]

$$\Rightarrow \quad v_e = R\sqrt{\frac{8}{3}\pi G\rho} \quad \ldots(i)$$

As it is given that the radius and mean density of planet are twice as that of earth. So, escape velocity at planet will be

$$v_p = 2R\sqrt{\frac{8}{3}\pi G 2\rho} \quad \ldots(ii)$$

Divide, Eq. (i) by Eq. (ii), we get

$$\frac{v_e}{v_p} = \frac{R\sqrt{\frac{8}{3}\pi G\rho}}{2R\sqrt{\frac{8}{3}\pi G 2\rho}}$$

$$\Rightarrow \quad \frac{v_e}{v_p} = \frac{1}{2\sqrt{2}}$$

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44 A satellite of mass m is orbiting the earth (of radius R) at a height h from its surface. The total energy of the satellite in terms of g_0, the value of acceleration due to gravity at the earth's surface is **[NEET 2016]**

(a) $\frac{mg_0R^2}{2(R+h)}$ (b) $-\frac{mg_0R^2}{2(R+h)}$

(c) $\frac{2mg_0R^2}{R+h}$ (d) $-\frac{2mg_0R^2}{R+h}$

Ans. *(b)*

$\because$ Total energy of a satellite at height h is

$$= \text{KE} + \text{PE} = \frac{GMm}{2(R+h)} - \frac{GMm}{(R+h)}$$

$$= \frac{-GMm}{2(R+h)} = \frac{-GMmR^2}{2R^2(R+h)} = \frac{-mg_0R^2}{2(R+h)}$$

$$\left(\because\ g_0 = \frac{GM}{R^2}\right)$$

45 A remote sensing satellite of earth revolves in a circular orbit at a height of 0.25×10^6 m above the surface of earth. If earth's radius is 6.38×10^6 m and $g = 9.8\ \text{ms}^{-2}$, then the orbital speed of the satellite is **[CBSE AIPMT 2015]**

(a) $7.76\ \text{kms}^{-1}$ (b) $8.56\ \text{kms}^{-1}$

(c) $9.13\ \text{kms}^{-1}$ (d) $6.67\ \text{kms}^{-1}$

Ans. *(a)*

Given, height of a satellite

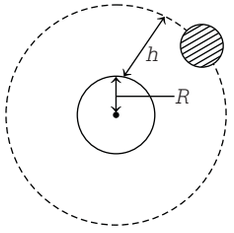
$h = 0.25 \times 10^6$ m

Earth's radius, $R_e = 6.38 \times 10^6$ m

For the satellite revolving around the earth, orbital velocity of the satellite

$$v_0 = \sqrt{\frac{GM_e}{R_e}} = \sqrt{\frac{GM_e}{R_e\left[1+\frac{h}{R_e}\right]}}$$

$$\Rightarrow\ v_0 = \sqrt{\frac{gR_e}{1+\frac{h}{R_e}}}$$



Substitutes the values of g, R_e and h, we get

$$v_0 = \sqrt{60 \times 10^6}\ \text{m/s}$$

$$v_0 = 7.76 \times 10^3 = 7.76\ \text{km/s}$$

46 A satellite S is moving in an elliptical orbit around the earth. The mass of the satellite is very small as compared to the mass of the earth. Then, **[CBSE AIPMT 2015]**

(a) the angular momentum of S about the centre of the earth changes in direction, but its magnitude remains constant

(b) the total mechanical energy of S varies periodically with time

(c) the linear momentum of S remains constant in magnitude

(d) the acceleration of S is always directed towards the centre of the earth

Ans. *(d)*

As we know that, force on satellite is only gravitational force which will always be towards the centre of earth. Thus, the acceleration of S is always directed towards the centre of the earth.

47 A black hole is an object whose gravitational field is so strong that even light cannot escape from it. To what approximate radius would earth (mass $= \mathbf{5.98} \times 10^{24}$ kg) have to be compressed to be a black hole? **[CBSE AIPMT 2014]**

(a) 10^{-9} m (b) 10^{-6} m

(c) 10^{-2} m (d) 10^{-7} m

Ans. *(c)*

Problem Solving Strategy For the black hole, the escape speed is more than c (speed of light). We should compare the escape speed with the c (Note that the escape speed should be at least just greater than c).

$$v_e = \sqrt{\frac{2GM}{R'}}$$

[R' = New radius of the earth]

$$c = \sqrt{\frac{2GM}{R'}}\ [v_e \approx c]\ \Rightarrow\ c^2 = 2\frac{GM}{R'}$$

$$R' = \frac{2GM}{c^2} = \frac{2 \times 6.67 \times 10^{-11} \times 6 \times 10^{24}}{9 \times 10^{16}}$$

$$= \frac{4 \times 6.67}{3} \times 10^{-3} = 8.89 \times 10^{-3}$$

$$= 0.889 \times 10^{-2} \simeq 10^{-2}\ \text{m}$$

48 The radii of circular orbits of two satellites A and B of the earth are $4R$ and R, respectively. If the speed of satellite A is $3v$, then the speed of satellite B will be **[CBSE AIPMT 2010]**

(a) $3v/4$ (b) $6\,v$ (c) $12\,v$ (d) $3v/2$

Ans. *(b)*

Orbital velocity of satellite is given by,

$$v = \sqrt{\frac{GM}{r}}$$

Ratio of orbital velocities of A and B is given by,

$$\Rightarrow\ \frac{v_A}{v_B} = \sqrt{\frac{r_B}{r_A}} = \sqrt{\frac{R}{4R}} = \frac{1}{2}$$

$$\therefore\ \frac{v_A}{v_B} = \frac{3v}{v_B} = \frac{1}{2}$$

$$\therefore\ v_B = 6v$$

49 The earth is assumed to be a sphere of radius R. A platform is arranged at a height R from the surface of the earth. The escape velocity of a body from this platform is fv_e, where v_e is its escape velocity from the surface of the earth. The value of f is **[CBSE AIPMT 2006]**

(a) $\sqrt{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) $\frac{1}{3}$ (d) $\frac{1}{2}$

Ans. *(b)*

At a platform at a height h,

Escape energy = binding energy of sphere

$$\text{or}\quad \frac{1}{2}m(fv_e)^2 = \frac{GMm}{R+h}$$

$$\text{or}\quad fv_e = \sqrt{\frac{2GM}{R+h}} = \sqrt{\frac{2GM}{2R}}\quad ...(\text{i})\quad (\because h = R)$$

But at surface of the earth,

$$v_e = \sqrt{\frac{2GM}{R}}\quad ...(\text{ii})$$

Dividing Eq. (ii) by Eq. (i).

$$\text{Hence,}\quad \frac{fv_e}{v_e} = \frac{\sqrt{\frac{GM}{R}}}{\sqrt{\frac{2GM}{R}}}\ \Rightarrow\ f = \frac{1}{\sqrt{2}}$$

50 For a satellite moving in an orbit around the earth, the ratio of kinetic energy to potential energy is **[CBSE AIPMT 2005]**

(a) 2 (b) 1/2 (c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$

Ans. *(b)*

Potential energy, $U = -\frac{GM_em}{R_e}$

where,

M_e = mass of the earth

m = mass of satellite

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R_e = radius of the earth

G = gravitational constant

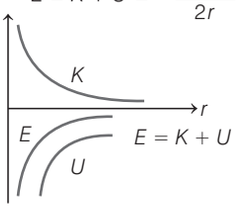
or $|U| = \frac{GM_e m}{R_e}$

Kineticenergy, $K = \frac{1}{2}\frac{GM_e m}{R_e}$

Thus, $\frac{K}{|U|} = \frac{1}{2}\frac{GM_e m}{R_e} \times \frac{R_e}{GM_e m} = \frac{1}{2}$

The total energy,

$$E = K + U = -\frac{GM_e m}{2r}$$



This energy is constant and negative, i.e. the system is closed. To farther the satellite from the earth, the greater is its total energy.

51 Escape velocity from the earth is 11.2 km/s. Another planet of same mass has radius 1/4 times that of the earth. What is the escape velocity from another planet?

[CBSE AIPMT 2000]

(a) 11.2 km/s (b) 44.8 km/s
(c) 22.4 km/s (d) 5.6 km/s

Ans. *(c)*

Problem Solving Strategy Compare the equation of escape velocity of earth and planet.

Escape velocity is given by,

$$v_{es} = \sqrt{\frac{2GM_e}{R_e}}$$

From a planet, $v'_{es} = \sqrt{\frac{2GM_p}{R_p}}$

Therefore, $\frac{v'_{es}}{v_{es}} = \sqrt{\frac{2GM_p}{R_p}} \times \sqrt{\frac{R_e}{2GM_e}}$

It is given that,

mass of the planet = mass of the earth

i.e. $M_p = M_e$

So, $\frac{v'_{es}}{v_{es}} = \sqrt{\frac{R_e}{R_p}}$ ...(i)

Given, $R_p = \frac{R_e}{4} \Rightarrow \frac{R_p}{R_e} = \frac{1}{4}$ and

$v_{es} = 11.2$ km/s

Substituting in Eq. (i), we have

$\frac{v'_{es}}{11.2} = \sqrt{\frac{4}{1}} = 2,$

$v'_{es} = 11.2 \times 2 = 22.4$ km/s

52 The escape velocity of a sphere of mass m is given by (G = universal gravitational constant, M_e = mass of the earth and R_e = radius of the earth) **[CBSE AIPMT 1999]**

(a) $\sqrt{\frac{GM_e}{R_e}}$ (b) $\sqrt{\frac{2GM_e}{R_e}}$
(c) $\sqrt{\frac{2Gm}{R_e}}$ (d) $\frac{GM_e}{R_e^2}$

Ans. *(b)*

The binding energy of sphere of mass m (say) on the surface of the earth kept at rest is $\frac{GM_e m}{R_e}$. To escape it from the earth's surface, this much energy in the form of kinetic energy is supplied to it.

So, $\frac{1}{2}mv_e^2 = \frac{GM_e m}{R_e}$

or v_e = escape velocity $= \sqrt{\frac{2GM_e}{R_e}}$

where, R_e = radius of earth,

M_e = mass of the earth.

53 The escape velocity of a body on the surface of the earth is 11.2 km/s. If the earth's mass increases to twice its present value and the radius of the earth becomes half, the escape velocity would become **[CBSE AIPMT 1997]**

(a) 44.8 km/s
(b) 22.4 km/s
(c) 11.2 km/s (remain unchanged)
(d) 5.6 km/s

Ans. *(b)*

Escape velocity on the earth's surface is given by

$$v_{es} = \sqrt{\frac{2GM_e}{R_e}}$$

where, G is gravitational constant, M_e and R_e are the mass and radius of the earth respectively. By taking the ratios of two different cases

$\therefore \quad \frac{v'_{es}}{v_{es}} = \sqrt{\frac{M'_e}{M_e} \times \frac{R_e}{R'_e}}$

but $M'_e = 2M_e$

and $R'_e = \frac{R_e}{2}$

$v_{es} = 11.2$ km/s.

$\therefore \quad \frac{v'_{es}}{v_{es}} = \sqrt{\frac{2M_e}{M_e} \times \frac{R_e}{R_e/2}} = \sqrt{4} = 2$

$\therefore \quad v'_{es} = 2v_{es} = 2 \times 11.2 = 22.4$ km/s

The escape velocity on moon's surface is only 2.5 km/s. This is the basic fundamental on which, absence of atmosphere on moon can be explained.

54 A ball is dropped from a satellite revolving around the earth at a height of 120 km. The ball will **[CBSE AIPMT 1996]**

(a) continue to move with same speed along a straight line tangentially to the satellite at that time
(b) continue to move with the same speed along the original orbit of satellite
(c) fall down to the earth gradually
(d) go far away in space

Ans. *(b)*

The ball, when dropped from the orbiting satellite will not reach the surface of the earth. When ball is dropped from the satellite, the ball also starts moving with the same speed due to inertia. As the orbit of a satellite does not depend upon its mass, the ball continues to move along with the satellite in the same orbit.

55 The escape velocity from the surface of the earth is v_e. The escape velocity from the surface of a planet whose mass and radius are three times those of the earth, will be **[CBSE AIPMT 1995]**

(a) v_e (b) $3v_e$ (c) $9v_e$ (d) $\frac{1}{3v_e}$

Ans. *(a)*

Escape velocity on surface of the earth is given by

$$v_e = \sqrt{2gR_e} = \sqrt{\frac{2GM_e}{R_e}} \qquad \left(\because g = \frac{GM_e}{R_e^2}\right)$$

where, M_e = mass of earth

R_e = radius of the earth

G = gravitational constant

$\therefore \quad v_e \propto \sqrt{\frac{M_e}{R_e}}$

If v_p is escape velocity from the surface of the planet, then $\frac{v_e}{v_p} = \sqrt{\frac{M_e}{R_e}} \times \sqrt{\frac{R_p}{M_p}}$

where, M_p is mass of the planet and R_p is radius of the planet.

but $R_p = 3R_e$ (given)

and $M_p = 3M_e$

$\therefore \quad \frac{v_e}{v_p} = \sqrt{\frac{M_e}{R_e}} \times \sqrt{\frac{3R_e}{3M_e}} = \frac{1}{1} = 1$ or $v_p = v_e$

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56 The escape velocity from the earth is 11.2 km/s. If a body is to be projected in a direction making an angle 45° to the vertical, then the escape velocity is **[CBSE AIPMT 1993]**

(a) 11.2×2 km/s (b) 11.2 km/s

(c) $\frac{11.2}{\sqrt{2}}$ km/s (d) $11.2\sqrt{2}$ km/s

Ans. *(b)*

As, $v_e = \sqrt{2gR} = \sqrt{\frac{2GM}{R}}$

Hence, escape velocity does not depend on the angle of projection. Escape velocity will remain same.

57 The mean radius of the earth is R, its angular speed on its own axis is ω and the acceleration due to gravity at the earth's surface is g. What will be the radius of the orbit of a geostationary satellite? **[CBSE AIPMT 1992]**

(a) $\left(\frac{R^2 g}{\omega^2}\right)^{1/3}$ (b) $\left(\frac{Rg}{\omega^2}\right)^{1/3}$

(c) $\left(\frac{R^2\omega^2}{g}\right)^{1/3}$ (d) $\left(\frac{R^2 g}{\omega}\right)^{1/3}$

Ans. *(a)*

Let v_o be orbital speed and be is the radius of orbit of a geostationary satellite. So, time period of satellite

$$T = \frac{2\pi r}{v_o}$$

As, $v_o = \sqrt{\frac{GM}{r}} = \sqrt{\frac{gR^2}{r}} \quad \left(\because g = \frac{GM}{R^2}\right)$

$$\therefore \quad T = \frac{2\pi r}{(gR^2/r)^{1/2}} z = \frac{2\pi r^{3/2}}{\sqrt{gR^2}}$$

but $T = \frac{2\pi}{\omega} \Rightarrow T = \frac{2\pi r^{3/2}}{\sqrt{gR^2}} = \frac{2\pi}{\omega}$

Hence, $r^{3/2} = \frac{\sqrt{gR^2}}{\omega}$ or $r^3 = \frac{gR^2}{\omega^2}$

or $r = \left(\frac{gR^2}{\omega^2}\right)^{1/3}$

58 The satellite of mass m is orbiting around the earth in a circular orbit with a velocity v. What will be its total energy? **[CBSE AIPMT 1991]**

(a) $\frac{3}{4}mv^2$ (b) $\frac{1}{2}mv^2$

(c) mv^2 (d) $-\left(\frac{1}{2}\right)mv^2$

Ans. *(d)*

Let satellite of mass m be revolving closely around the earth of mass M and radius R.

Total energy of satellite

$$= \text{PE} + \text{KE} = -\frac{GMm}{R} + \frac{1}{2}mv^2$$

$$= -\frac{GMm}{R} + \frac{m}{2}\frac{GM}{R} \left[\text{as } v = \sqrt{\frac{GM}{R}}\right]$$

$$= -\frac{GMm}{2R}$$

$\therefore$ Total energy of satellite $= -\frac{1}{2}mv^2$

59 For a satellite escape velocity is 11 km/s. If the satellite is launched at an angle of 60° with the vertical, then escape velocity will be **[CBSE AIPMT 1989]**

(a) 11 km/s (b) $11\sqrt{3}$ km/s

(c) $\frac{11}{\sqrt{3}}$ km/s (d) 33 km/s

Ans. *(a)*

Escape velocity on earth (or any other planet) is defined as the minimum velocity with which the body has to be projected vertically upwards from the surface of the earth (or any other planet). So, that it just crosses the gravitational field of earth and never returns on its own. The escape velocity of the earth is given by

$$v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$$

$$= \sqrt{\frac{8\pi\rho GR^2}{3}}$$

From above equation it is clear that value of escape velocity of a body does not depend upon the mass (m) of the body and its angle of projection from the surface of the earth or the planet. So, escape velocity remains same.

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08

Mechanical Properties of Solids

TOPIC 1

Stress, Strain and Hooke's Laws

01 A wire of length L, area of cross-section A is hanging from a fixed support. The length of the wire changes to L_1 when mass M is suspended from its free end. The expression for Young's modulus is **[NEET (Sep.) 2020]**

(a) $\frac{Mg(L_1-L)}{AL}$ (b) $\frac{MgL}{AL_1}$

(c) $\frac{MgL}{A(L_1-L)}$ (d) $\frac{MgL_1}{AL}$

Ans. *(c)*

Here, change in length, $\Delta L = (L_1 - L)$

Area $= A$

Force, $F = Mg$

Young's modulus, $Y = \frac{\text{Normal stress}}{\text{Longitudinal strain}}$

$$\Rightarrow \quad Y = \frac{(F/A)}{\left(\frac{\Delta L}{L}\right)} = \frac{\frac{Mg}{A}}{\left(\frac{L_1 - L}{L}\right)}$$

$$= \frac{MgL}{A(L_1 - L)}$$

Hence, correct option is (c).

02 Two wires are made of the same material and have the same volume. The first wire has cross-sectional area A and the second wire has cross-sectional area $3A$. If the length of the first wire is increased by Δl on applying a force F, how much force is needed to stretch the second wire by the same amount? **[NEET 2018]**

(a) $4F$ (b) $6F$ (c) $9F$ (d) F

Ans. *(c)*

According to the question,

For wire 1

Area of cross-section $= A_1$

Force applied $= F_1$

Increase in length $= \Delta l$

From the relation of Young's modulus of elasticity,

$$Y = \frac{Fl}{A\Delta l}$$

Substituting the values for wire 1 in the above relation, we get

$$\Rightarrow \quad Y_1 = \frac{F_1 l_1}{A_1 \Delta l} \qquad ...(i)$$

For wire 2

Area of cross-section $= A_2$

Force applied $= F_2$

Increase in length $= \Delta l$

Similarly,

$$Y_2 = \frac{F_2 l_2}{A_2 \Delta l} \qquad ...(ii)$$

$\because$ Volume, $V = Al$

or $l = \frac{V}{A}$

Substituting the value of l in Eqs. (i) and (ii), we get

$$Y_1 = \frac{F_1 V}{A_1^2 \Delta l} \quad \text{and} \quad Y_2 = \frac{F_2 V}{A_2^2 \Delta l}$$

As it is given that the wires are made up of same material, i.e. $Y_1 = Y_2$

$$\Rightarrow \quad \frac{F_1 V}{A_1^2 \Delta l} = \frac{F_2 V}{A_2^2 \Delta l}$$

$$\Rightarrow \quad \frac{F_1}{F_2} = \frac{A_1^2}{A_2^2} = \frac{A^2}{9A^2} \quad (\because A_1 = A \text{ and } A_2 = 3A)$$

$$= \frac{1}{9}$$

or $F_2 = 9F_1 = 9F$ (given, $F_1 = F$)

03 The bulk modulus of a spherical object is B. If it is subjected to uniform pressure p, the fractional decrease in radius is **[NEET 2017]**

(a) $\frac{p}{B}$ (b) $\frac{B}{3p}$

(c) $\frac{3p}{B}$ (d) $\frac{p}{3B}$

Ans. *(d)*

The object is spherical and the bulk modulus is represented by B. It is the ratio of normal stress to the volumetric strain.

Hence $B = \frac{F/A}{\Delta V/V} \Rightarrow \frac{\Delta V}{V} = \frac{p}{B}$

$$\Rightarrow \quad \left|\frac{\Delta V}{V}\right| = \frac{p}{B}$$

Here p is applied pressure on the object and $\frac{\Delta V}{V}$ is volume strain

Fractional decreases in volume

$$\Rightarrow \quad \frac{\Delta V}{V} = 3\frac{\Delta R}{R} \qquad [\because V = \frac{4}{3}\pi R^3]$$

Volume of the sphere decreases due to the decrease in its radius.

Hence $\frac{\Delta V}{V} = \frac{3\Delta R}{R} = \frac{p}{B}$

$$\Rightarrow \quad \frac{\Delta R}{R} = \frac{p}{3B}$$

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04 Copper of fixed volume V is drawn into wire of length l. When this wire is subjected to a constant force F, the extension produced in the wire is Δl. Which of the following graphs is a straight line? **[CBSE AIPMT 2014]**

(a) Δl *versus* $\frac{1}{l}$ (b) Δl *versus* l^2

(c) Δl *versus* $\frac{1}{l^2}$ (d) Δl *versus* l

Ans. ***(b)***

Youngs' modulus is given by

$$Y = \frac{F \times l}{A \times \Delta l} \quad ...(i)$$

As $V = A \times l$ = constant ...(ii)

From Eqs. (i) and (ii), we get

$$Y = \frac{F \times l^2}{V \times \Delta l} \Rightarrow \Delta l = \frac{F}{V \times Y} \times l^2$$

$$\Rightarrow \Delta l \propto l^2$$

05 The following four wires are made of same material. Which of these will have the largest extension when the same tension is applied? **[NEET 2013]**

(a) Length = 50 cm, diameter = 0.5 mm
(b) Length = 100 cm, diameter = 1 mm
(c) Length = 200 cm, diameter = 2 mm
(d) Length = 300 cm, diameter = 3 mm

Ans. ***(a)***

As $\gamma = \frac{F \times L}{\Delta L \times A} = \frac{mg \cdot L}{\Delta L \cdot A}$ or $\Delta L = \frac{mgL}{\gamma \cdot A}$

$\Rightarrow \Delta L \propto \frac{L}{A}$, which is maximum for option (a).

TOPIC 2

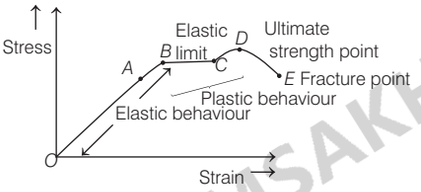
Stress-Strain Curve, Thermal Stress and Elastic PE

06 The stress-strain curves are drawn for two different materials X and Y. It is observed that the ultimate strength point and the fracture point are close to each other for material X but are far apart for material Y. We can say that materials X and Y are likely to be (respectively) **[NEET (Odisha) 2019]**

(a) ductile and brittle
(b) brittle and ductile
(c) brittle and plastic
(d) plastic and ductile

Ans. ***(b)***

The stress-strain curve for a material is shown



This curve specifies the behaviour of material.

For the material, if distance between strength point and fracture point is small, so it is brittle and will break easily on the application of some extra stress after point D.

For material Y, if the distance between strength point and fracture point is large, so it is a ductile material and can withstand for some extra stress beyond point D.

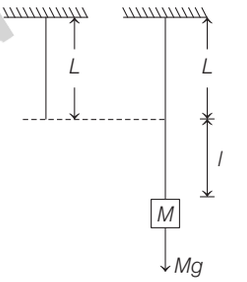
07 When a block of mass M is suspended by a long wire of length L, the length of the wire becomes $(L + l)$. The elastic potential energy stored in the extended wire is **[NEET (National) 2019]**

(a) MgL (b) $\frac{1}{2}Mgl$

(c) $\frac{1}{2}MgL$ (d) Mgl

Ans. ***(b)***

In stretching a wire, the work done against internal restoring force is stored as elastic potential energy in wire and given by



$$U = W = \frac{1}{2} \times \text{Force}(F) \times \text{Elongation}(l)$$

$$= \frac{1}{2}Fl = \frac{1}{2} \times Mg \times l = \frac{1}{2}Mgl$$

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09

Mechanical Properties of Fluids

TOPIC 1
Pressure and Pascal's Law

01 A barometer is constructed using a liquid (density = 760 kg/m^3). What would be the height of the liquid column, when a mercury barometer reads 76 cm? (Density of mercury = 13600 kg/m^3)

[NEET (Oct.) 2020]

(a) 1.36 m
(b) 13.6 m
(c) 136 m
(d) 0.76 m

Ans. *(b)*

Density of liquid, $\rho_l = 760$ kg /m^3
Density of mercury, $\rho_m = 13600$ kg /m^3
Height of liquid column in mercury barometer,

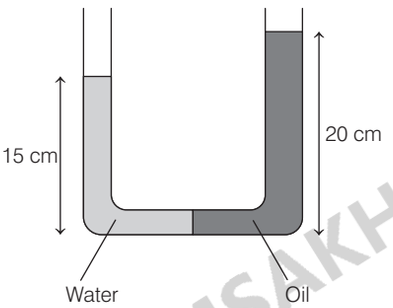
$$h_m = 76 \text{ cm} = 0.76 \text{ m}$$

If height of liquid in liquid column be h_l, then

$$p_{\text{liquid}} = p_{\text{mercury}}$$
$$\Rightarrow \quad h_l \rho_l g = h_m \rho_m g$$
$$\Rightarrow \quad h_l = \frac{h_m \rho_m}{\rho_l} = \frac{0.76 \times 13600}{760}$$
$$= 13.6 \text{ m}$$

02 In a *U*-tube as shown in a figure, water and oil are in the left side and right side of the tube respectively. The heights from the bottom for water and oil columns are 15 cm and 20 cm respectively. The density of the oil is [take $\rho_{\text{water}} = 1000$ kg/m^3]

[NEET (Odisha) 2019]

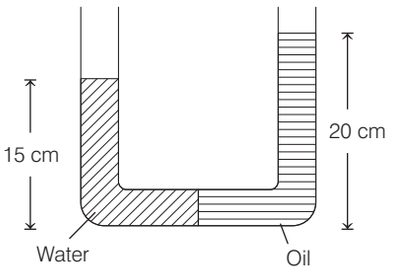


(a) 1200 kg/m^3 (b) 750 kg/m^3
(c) 1000 kg/m^3 (d) 1333 kg/m^3

Ans. *(b)*

According to Pascal's law "Pressure applied to an enclosed fluid is transmitted undiminished to every point of the fluid and the walls of the containing vessel."

In the given situation as shown in the figure below

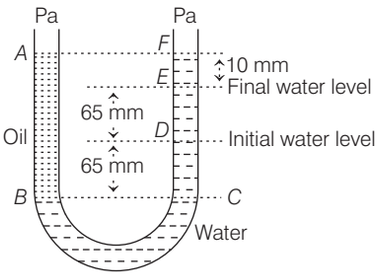


Pressure due to water column of height 15 cm = Pressure due to oil column of height 20 cm

$$\Rightarrow \quad h_w \rho_w g = h_0 \rho_0 g$$
$$15 \rho_w = 20 \rho_0$$
$$\Rightarrow \quad \rho_0 = \frac{15}{20} \rho_\omega$$
$$\rho_0 = \frac{15}{20} \times 1000$$
$$(\because \text{given}, \rho_w = 1000 \text{ kg m}^{-3})$$
$$= 750 \text{ kgm}^{-3}$$

03 A U tube with both ends open to the atmosphere, is partially filled with water. Oil, which is immiscible with water, is poured into one side until it stands at a distance of 10 mm above the water level on the other side. Meanwhile the water rises by 65 mm from its original level (see diagram). The density of the oil is

[NEET 2017]



(a) 650 kg m^{-3} (b) 425 kg m^{-3}
(c) 800 kg m^{-3} (d) 928 kg m^{-3}

Ans. *(d)*

Thinking Process Pressure of two points lie in the same horizontal level should be same and $p = hdg$

Both ends of the U tube are open, so the pressure on both the free surfaces must be equal.

i.e., $p_1 = p_2$

$$h_{\text{oil}} \cdot S_{\text{oil}}\, g = h_{\text{water}} \cdot S_{\text{water}} \cdot g$$

S_{oil} = specific density of oil

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$$S_{oil} = \frac{h_{water} \cdot S_{water} \cdot g}{h_{oil} \cdot g}$$

From figure $S_{oil} = \frac{(65+65)\times 1000}{(65+65+10)}$

$= 928\ kgm^{-3}$

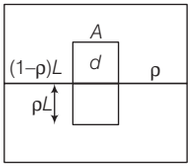
04 Two non-mixing liquids of densities ρ and $n\rho(n>1)$ are put in a container. The height of each liquid is h. A solid cylinder of length L and density d is put in this container. The cylinder floats with its axis vertical and length pL $(p<1)$ in the denser liquid. The density d is equal to **[NEET 2016]**

(a) $\{2+(n+1)p\}\rho$ (b) $\{2+(n-1)p\}\rho$

(c) $\{1+(n-1)p\}\rho$ (d) $\{1+(n+1)p\}\rho$

Ans. *(c)*

According to question, the situation can be drawn as following.



Applying Archemedies principle

Weight of cylinder

$= (\text{upthrust})_1 + (\text{upthrust})_2$

i.e. $ALdg = (1-P)LA\rho g + (PLA)n\rho g$

$\Rightarrow \quad d = (1-P)\rho + Pn\rho$

$= \rho - P\rho + nP\rho$

$= \rho + (n-1)P\rho = \rho[1+(n-1)\rho]$

05 The approximate depth of an ocean is 2700 m. The compressibility of water is $45.4\times10^{-11}\ Pa^{-1}$ and density of water is $10^3\ kg/m^3$. What fractional compression of water will be obtained at the bottom of the ocean? **[CBSE AIPMT 2015]**

(a) 0.8×10^{-2} (b) 1.0×10^{-2}

(c) 1.2×10^{-2} (d) 1.4×10^{-2}

Ans. *(c)*

Given $d = 2700$ m $\Rightarrow \rho = 10^3\ kg/m^3$

Compressibility $= 45.4\times10^{-11}$ per pascal

The pressure at the bottom of ocean is given by

$p = \rho g d$

$= 10^3\times10\times2700 = 27\times10^6$ Pa

So, fractional compression

= compressibility × pressure

$= 45.4\times10^{-11}\times27\times10^6 = 1.2\times10^{-2}$

TOPIC 2
Bernoullis Principle and Viscosity

06 The velocity of a small ball of mass M and density d when dropped in a container filled with glycerine becomes constant after some time. If the density of glycerine is $d/2$, then the viscous force acting on the ball will be **[NEET 2021]**

(a) $\frac{Mg}{2}$ (b) Mg

(c) $\frac{3}{2}Mg$ (d) $2Mg$

Ans. *(a)*

Given, the density of the small ball is d

The mass of the small ball is M

The density of the glycerine is $d/2$.

As we know that,

viscous force = weight – buoyant force

Viscous force $= Vd_1g - Vd_2g$

Here, V is the volume of submerged bodies,

g is the acceleration due to gravity,

d_1 is the density of the small ball,

d_2 is the density of the glycerine,

$d_1 = d$ and $d_2 = d/2$

Substituting the given values in the viscous force expression, we get

Viscous force $= Vdg - V\frac{d}{2}g$

Viscous force $= \frac{Vdg}{2} = \frac{Mg}{2}$ $(\because M = d\times V)$

07 Two small spherical metal balls, having equal masses, are made from materials of densities ρ_1 and ρ_2 $(\rho_1 = 8\rho_2)$ and have radii of 1 mm and 2 mm, respectively. They are made to fall vertically (from rest) in viscous medium whose coefficient of viscosity equals η and whose density is $0.1\rho_2$. The ratio of their terminal velocities would be **[NEET (Odisha) 2019]**

(a) $\frac{79}{72}$ (b) $\frac{19}{36}$ (c) $\frac{39}{72}$ (d) $\frac{79}{36}$

Ans. *(d)*

The terminal velocity achieved by ball in a viscous fluid is

$$v_t = \frac{2(\rho-\sigma)r^2 g}{9\eta}$$

where, ρ = density of metal of ball,

σ = density of viscous medium,

r = radius of ball and

η = coefficient of viscosity of medium

Terminal velocity of first ball,

$$v_{t_1} = \frac{2(\rho_1-\sigma)r_1^2 g}{9\eta} = \frac{2(8\rho_2-\sigma)r_1^2 g}{9\eta} \quad ...(i)\ [\because \rho_1 = 8\rho_2]$$

Similarly, for second ball

$$v_{t_2} = \frac{2(\rho_2-\sigma)r_2^2 g}{9\eta} \quad ...(ii)$$

From Eq. (i) and (ii), we get

$$\frac{v_{t_1}}{v_{t_2}} = \frac{2(8\rho_2-\sigma)r_1^2 g}{2(\rho_2-\sigma)r_2^2 g}\times\frac{9\eta}{9\eta} = \left(\frac{8\rho_2-0.1\rho_2}{\rho_2-0.1\rho_2}\right)\left(\frac{r_1}{r_2}\right)^2 \quad ...(iii)\ [\because \sigma = 0.1\rho_2]$$

Here, $r_1 = 1$ mm and $r_2 = 2$ mm

Substituting these values in Eq. (iii), we get

$$\Rightarrow \quad \frac{v_{t_1}}{v_{t_2}} = \left(\frac{7.9\rho_2}{0.9\rho_2}\right)\left(\frac{1}{2}\right)^2 = \frac{79}{36}$$

08 A small hole of area of cross-section 2 mm^2 is present near the bottom of a fully filled open tank of height 2 m. Taking $g = 10\ m/s^2$, the rate of flow of water through the open hole would be nearly **[NEET (National) 2019]**

(a) $8.9\times10^{-6} m^3/s$

(b) $2.23\times10^{-6}\ m^3/s$

(c) $6.4\times10^{-6}\ m^3/s$

(d) $12.6\times10^{-6}\ m^3/s$

Ans. *(d)*

The rate of liquid flow moving with velocity v through an area a is given by

Rate (R) = Area (a) × Velocity (v)

Given, area of hole,

$a = 2\ mm^2$

$= 2\times10^{-6}\ m^2$

height of tank, $h = 2$ m.

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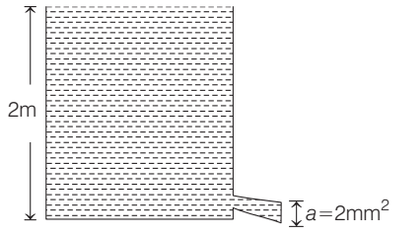
The given situation can also be depicted as shown in the figure below.



As the velocity of liquid flow is given as $v=\sqrt{2gh}$

$\therefore R=av=a\sqrt{2gh}$

Substituting the given values, we get

$$R=2\times10^{-6}\times\sqrt{2\times10\times2}$$
$$=2\times10^{-6}\times6.32=12.64\times10^{-6}\ \text{m}^3/\text{s}$$
$$\simeq 12.6\times10^{-6}\ \text{m}^3/\text{s}$$

09 A small sphere of radius r falls from rest in a viscous liquid. As a result, heat is produced due to viscous force. The rate of production of heat when the sphere attains its terminal velocity, is proportional to **[NEET 2018]**

(a) r^5 (b) r^2
(c) r^3 (d) r^4

Ans. *(a)*

Key Concept The rate of heat generation is equal to the rate of work done by the viscous force which in turn is equal to its power.

Rate of heat produced, $\frac{dQ}{dt}=F\times v_T$

where, F is the viscous force and v_T is the terminal velocity.

As, $F=6\pi\eta r v_T$

$$\Rightarrow \frac{dQ}{dt}=6\pi\eta r v_T\times v_T$$
$$=6\pi\eta r v_T^2 \quad ...(i)$$

From the relation for terminal velocity,

$v_T=\frac{2}{9}\frac{r^2(\rho-\sigma)}{\eta}g$, we get

$$v_T\propto r^2 \quad ...(ii)$$

From Eq. (ii), we can rewrite Eq. (i) as

$$\frac{dQ}{dt}\propto r\cdot(r^2)^2$$

or $$\frac{dQ}{dt}\propto r^5$$

10 A wind with speed 40 m/s blows parallel to the roof of a house. The area of the roof is 250 m². Assuming that the pressure inside the house is atmospheric pressure, the force exerted by the wind on the roof and the direction of the force will be ($\rho_{air}=1.2\ \text{kg/m}^3$) **[CBSE AIPMT 2015]**

(a) 4.8×10^5 N, downwards
(b) 4.8×10^5 N, upwards
(c) 2.4×10^5 N, upwards
(d) 2.4×10^5 N, downwards

Ans. *(c)*

From Bernoulli's theorem

$$p_1+\frac{1}{2}\rho v_1^2=p_2+\frac{1}{2}\rho v_2^2$$

where, p_1, p_2 are pressure inside and outside the roof and v_1, v_2 are velocities of wind inside and outside the roof.

Neglect the width of the roof.

Pressure difference is

$$p_1-p_2=\frac{1}{2}\rho(v_2^2-v_1^2)$$
$$=\frac{1}{2}\times1.2(40^2-0)$$
$$=960\ \text{N/m}^2$$

Force acting on the roof is given by

$$F=(p_1-p_2)A=960\times250$$
$$=24\times10^4\text{N}=2.4\times10^5\ \text{N}$$

As the pressure inside the roof is more than outside to it. So the force will act in the upward direction,

i.e. $\mathbf{F}=2.4\times10^5$ N- upwards.

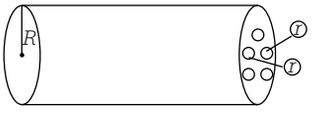
11 The cylindrical tube of a spray pump has radius R, one end of which has n fine holes, each of radius r. If the speed of the liquid in the tube is v, the speed of the ejection of the liquid through the holes is **[CBSE AIPMT 2015]**

(a) $\frac{vR^2}{n^2r^2}$ (b) $\frac{vR^2}{nr^2}$ (c) $\frac{vR^2}{n^3r^2}$ (d) $\frac{v^2R}{nr}$

Ans. *(b)*

Key Concept During the streamline flow of viscous and incompressible fluid through a pipe varying cross-section, the product of area of cross-section and normal fluid velocity (Av) remains constant throughout the flow.

Consider a cylindrical tube of a spray pump has radius R, one end having n fine holes, each of radius r and speed of liquid in the tube is v as shown in figure.



According to equation of continuity,

Av = constant

where, A is a cylindrical tube and v is velocity of liquid in a tube.

Volume in flow rate

= volume in out flow rate

$$\pi R^2v=n\,\pi r^2v' \Rightarrow v'=\frac{R^2v}{nr^2}$$

Thus, speed of the ejection of the liquid through the holes is $\frac{R^2v}{nr^2}$.

TOPIC 3
Surface Tension, Excess Pressure and Capillarity

12 A liquid does not wet the solid surface if angle of contact is **[NEET (Oct.) 2020]**

(a) equal to 45°
(b) equal to 60°
(c) greater than 90°
(d) zero

Ans. *(c)*

A liquid does not wet the solid surface, if the angle of contact is obtuse i.e., $\theta>90^\circ$.

13 A capillary tube of radius r is immersed in water and water rises in it to a height h. The mass of the water in the capillary tube is 5 g. Another capillary tube of radius $2r$ is immersed in water. The mass of water that will rise in this tube is **[NEET (Sep.) 2020]**

(a) 5.0 g (b) 10.0 g
(c) 20.0 g (d) 2.5 g

Ans. *(d)*

Relation for height of water in capillary tube is

$$h=\frac{2S\cos\theta}{\rho gr}$$

$$\Rightarrow h\propto\frac{1}{r}$$

$$\Rightarrow \frac{h_1}{h_2}=\frac{r_2}{r_1}=\frac{2r}{r}=2$$

As $m=A\cdot h\cdot\rho$

$$\therefore \frac{m_2}{m_1}=\frac{Ah_2\rho}{Ah_1\rho}=\frac{h_2}{h_1}=\frac{1}{2}$$

$$\Rightarrow m_2=\frac{m_1}{2}=\frac{5}{2}=2.5\text{g}$$

Hence, correct option is (d).

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14 A soap bubble, having radius of 1 mm, is blown from a detergent solution having a surface tension of 2.5×10^{-2} N/m. The pressure inside the bubble equals at a point Z_0 below the free surface of water in a container. Taking $g=10\,m/s^2$, density of water $=10^3\,kg/m^3$, the value of Z_0 is **[NEET (National) 2019]**

(a) 10 cm
(b) 1 cm
(c) 0.5 cm
(d) 100 cm

Ans. ***(b)***

The excess pressure inside a soap bubble of radius r is given by

$$p=\frac{4T}{r}$$

where, T = surface tension.

If p_0 be the outside pressure from the water, then total pressure inside the bubble becomes

$$p_1=p_0+\frac{4T}{r} \quad \ldots(i)$$

The pressure at the depth Z_0 below the water surface is

$$p_2=p_0+Z_0\rho g \quad \ldots(ii)$$

As it is given that the pressure inside the bubble is same as the pressure at depth Z_0, then equating

Eqs. (i) and (ii), we get

$$p_0+\frac{4T}{r}=p_0+Z_0\rho g$$

$$\Rightarrow \quad Z_0=\frac{4T}{r\rho g} \quad \ldots(iii)$$

Here, $T=2.5\times10^{-2}$ N/m, $\rho=10^3$ kg/m^3, $g=10\,ms^{-2}$ and $r=1\,mm=1\times10^{-3}$ m

Substituting these values in Eq. (iii), we get

$$Z_0=\frac{4\times2.5\times10^{-2}}{1\times10^{-3}\times10^3\times10}$$

$$=10\times10^{-3}\text{ m}$$

$$=1\text{ cm}$$

15 A rectangular film of liquid is extended from (4 cm × 2 cm) to (5 cm × 4 × cm). If the work done is 3×10^{-4} J, the value of the surface tension of the liquid is **[NEET 2016]**

(a) 0.250 Nm^{-1} (b) 0.125 Nm^{-1}
(c) 0.2 Nm^{-1} (d) 8.0 Nm^{-1}

Ans. ***(b)***

Key Idea Increase in surface energy = work done in area × surface tension

$\because$ Increase in surface area,

$\Delta A=(5\times4-4\times2)\times2$

($\because$ film has two surfaces)

$=(20-8)\times2\text{ cm}^2=24\text{ cm}^2$

$=24\times10^{-4}\text{ m}^2$

So, work done, $W=T\cdot\Delta A$

$$3\times10^{-4}=T\times24\times10^{-4}$$

$$\therefore \quad T=\frac{1}{8}=0.125\text{ N/m}$$

16 Three liquids of densities ρ_1,ρ_2 and ρ_3 (with $\rho_1>\rho_2>\rho_3$), having the same value of surface tension T, rise to the same height in three identical capillaries. The angles of contact θ_1,θ_2 and θ_3 obey **[NEET 2016]**

(a) $\frac{\pi}{2}>\theta_1>\theta_2>\theta_3\geq0$

(b) $0\leq\theta_1<\theta_2<\theta_3<\frac{\pi}{2}$

(c) $\frac{\pi}{2}<\theta_1<\theta_2<\theta_3<\pi$

(d) $\pi>\theta_1>\theta_2>\theta_3>\frac{\pi}{2}$

Ans. ***(b)***

According to ascent formula for capillary tube,

$$h=\frac{2T\cos\theta}{\rho gr}$$

$$\therefore \quad \frac{\cos\theta_1}{\rho_1}=\frac{\cos\theta_2}{\rho_2}=\frac{\cos\theta_3}{\rho_3}$$

Thus, $\cos\theta\propto\rho$

$$\therefore \quad \rho_1>\rho_2>\rho_3$$

$$\therefore \quad \cos\theta_1>\cos\theta_2>\cos\theta_3$$

$$0\leq\theta_1<\theta_2<\theta_3<\frac{\pi}{2}$$

17 A certain number of spherical drops of a liquid of radius r coalesce to form a single drop of radius R and volume V. If T is the surface tension of the liquid, then **[CBSE AIPMT 2014]**

(a) energy $=4VT\left(\frac{1}{r}-\frac{1}{R}\right)$ is released

(b) energy $=3VT\left(\frac{1}{r}+\frac{1}{R}\right)$ is absorbed

(c) energy $=3VT\left(\frac{1}{r}-\frac{1}{R}\right)$ is released

(d) energy is neither released nor absorbed

Ans. ***(c)***

As energy released $=(A_f-A_i)T$

where, $A_i=4\pi R^2=\frac{3}{3}\times4\pi\frac{R^3}{R}=\frac{3V}{R}$

and $A_f=4\pi r^2=\frac{V}{\frac{4}{3}\pi r^2}4\pi r^2=\frac{3V}{r}$

$\therefore$ Energy released $=3VT\left[\frac{1}{r}-\frac{1}{R}\right]$

18 The wettability of a surface by a liquid depends primarily on **[NEET 2013]**

(a) viscosity
(b) surface tension
(c) density
(d) angle of contact between the surface and the liquid

Ans. ***(d)***

The wettability of a surface by a liquid depends primarily on angle of contact between the surface and the liquid.

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10

Thermal Properties of Matter

TOPIC 1
Thermometry and Thermal Expansion

01 A copper rod of 88 cm and an aluminium rod of unknown length have their increase in length independent of increase in temperature. The length of aluminium rod is **[NEET (National) 2019]**

(a) 113.9 cm
(b) 88 cm
(c) 68 cm
(d) 6.8 cm

Ans. *(c)*

Due to change in temperature, the thermal strain produced in a rod of length L is given by

$$\frac{\Delta L}{L} = \alpha\,\Delta T$$

$$\Rightarrow \quad \Delta L = L\,\alpha\,\Delta T$$

where l = original length of rod and α = coefficient of liner expansion of solid rod

As the change in length (Δl) of the given two rods of copper and aluminium are independent of temperature change, i.e. ΔT is same for both copper and aluminium.

$$L_{Cu}\alpha_{Cu} = L_{Al}\alpha_{Al} \qquad \ldots (i)$$

Here, $\alpha_{Cu} = 1.7\times 10^{-5}\ K^{-1}$

$\alpha_{Al} = 2.2\times 10^{-5}\ K^{-1}$

and $L_{Cu} = 88$ cm

Substituting the given values in Eq. (i), we get

$$L_{Al} = \frac{L_{Cu}\alpha_{Cu}}{\alpha_{Al}} = \frac{1.7\times 10^{-5}\times 88}{2.2\times 10^{-5}} \simeq 68\text{ cm}$$

02 Coefficient of linear expansion of brass and steel rods are α_1 and α_2. Lengths of brass and steel rods are l_1 and l_2 respectively. If $(l_2 - l_1)$ is maintained same at all temperatures, which one of the following relations holds good ? **[NEET 2016]**

(a) $\alpha_1 l_2^2 = \alpha_2 l_1^2$ (b) $\alpha_1^2 l_2 = \alpha_2^2 l_1$
(c) $\alpha_1 l_1 = \alpha_2 l_2$ (d) $\alpha_1 l_2 = \alpha_2 l_1$

Ans. *(c)*

According to question,

Coefficient of linear expression of brass $= \alpha_1$

Coefficient of linear expression of steel $= \alpha_2$

Length of brass and steel rods are l_1 and l_2 respectively.

As given difference increase in length $(l_2' - l_1')$ is same for all temperature.

So, $l_2' - l_1' = l_2 - l_1$

$\Rightarrow \quad l_2(1+\alpha_2\Delta t) - l_1(1+\alpha_1\Delta t) = l_2 - l_1$

$\Rightarrow \quad l_2\alpha_2 = l_1\alpha_1$

03 The value of coefficient of volume expansion of glycerin is $5\times 10^{-4}\ K^{-1}$. The fractional change in the density of glycerin for a rise of 40°C in its temperature is **[CBSE AIPMT 2015]**

(a) 0.015 (b) 0.020 (c) 0.025 (d) 0.010

Ans. *(b)*

Given, the value of coefficient of volume expansion of glycerin is $5\times 10^{-4}\ K^{-1}$.

As, orginal density of glycerin,

$$\rho = \rho_0(1+\gamma\Delta T)$$

$$\Rightarrow \quad \rho - \rho_0 = \rho_0\gamma\Delta T$$

Thus, fractional change in the density of glycerine for a rise of 40°C in its temperature,

$$\frac{\rho-\rho_0}{\rho_0} = \gamma\Delta T = 5\times 10^{-4}\times 40$$

$$= 200\times 10^{-4} = 0.020$$

04 On a new scale of temperature (which is linear) and called the W scale, the freezing and boiling points of water are 39°W and 239°W respectively. What will be the temperature on the new scale, corresponding to a temperature of 39°C on the celsius scale ? **[CBSE AIPMT 2008]**

(a) 78°W (b) 117°W
(c) 200°W (d) 139°W

Ans. *(b)*

The relation between true scale and new scale of temperature is given by

$$\left(\frac{t-\text{LFP}}{\text{UFP}-\text{LFP}}\right)_{\text{true}} = \left(\frac{t-\text{LFP}}{\text{UFP}-\text{LFP}}\right)_{\text{faulty}}$$

$$\frac{39^\circ\text{C}-0^\circ\text{C}}{100^\circ\text{C}-0^\circ\text{C}} = \frac{t-39^\circ\text{W}}{239^\circ\text{W}-39^\circ\text{W}}$$

$$\Rightarrow \qquad t = 117^\circ\text{W}$$

05 The coefficients of linear expansions of brass and steel are α_1 and α_2 respectively. When we take a brass rod of length l_1 and a steel rod of length l_2 at 0°C, then the difference in their lengths $(l_2 - l_1)$ will remain the same at all temperatures, if **[CBSE AIPMT 1999]**

(a) $\alpha_1 l_1 = \alpha_2 l_2$ (b) $\alpha_1 l_2 = \alpha_2 l_1$
(c) $\alpha_1^2 l_2 = \alpha_2^2 l_1$ (d) $\alpha_1 l_2^2 = \alpha_2 l_1^2$

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Ans. *(a)*

Coefficient of linear expansion $= \frac{\text{Change in length}}{\text{Original length} \times \text{rise in temperature}}$

i.e. $\alpha = \frac{\Delta l}{lt}$

or $\Delta l = l\alpha t$

For brass rod, $\Delta l_1 = l_1\alpha_1 t$

For steel rod, $\Delta l_2 = l_2\alpha_2 t$

Since, $l_2 - l_1 = \text{constant}$ (given)

So, $\Delta l_2 - \Delta l_1 = 0$

or $\Delta l_2 = \Delta l_1$

$\therefore$ $l_2\alpha_2 t = l_1\alpha_1 t$

As $t \neq 0$, hence $l_2\alpha_2 = l_1\alpha_1$

06. Mercury thermometer can be used to measure temperature upto **[CBSE AIPMT 1992]**

(a) 260°C (b) 100°C
(c) 360°C (d) 500°C

Ans. *(c)*

Mercury thermometer is a liquid thermometer and it is based upon the uniform variation in volume of a liquid with temperature. Mercury is opaque and bright and therefore can be easily seen in the glass tube and it is good conductor of heat and attains the temperature of the hot bath quickly. A mercury thermometer can be used to measure temperature upto 300°C or so, as before boiling at 367°C, the vaporisation of mercury will start.

07. A Centigrade and a Fahrenheit thermometer are dipped in boiling water. The water temperature is lowered until the Fahrenheit thermometer registers 140°. What is the fall in temperature as registered by the Centigrade thermometer? **[CBSE AIPMT 1990]**

(a) 80° (b) 60° (c) 40° (d) 30°

Ans. *(c)*

Relation between Celsius scale and Fahrenheit scale is

$$\frac{C}{100} = \frac{F-32}{180}$$

Putting value of $F = 140°$

$\therefore$ $\frac{C}{100} = \frac{140-32}{180} = 0.6$

$\therefore$ $C = 60°$

Hence, fall in temperature = Temperature of boiling water − final temperature

$100°C - 60°C = 40°C$

TOPIC 2
Specific Heat Capacity, Calorimetry and Change of State

08 The quantities of heat required to raise the temperature of two solid copper spheres of radii r_1 and r_2 ($r_1 = 1.5r_2$) through 1 K are in the ratio **[NEET (Sep.) 2020]**

(a) $\frac{9}{4}$ (b) $\frac{3}{2}$ (c) $\frac{5}{3}$ (d) $\frac{27}{8}$

Ans. *(d)*

Since, heat required, $Q = mc\Delta T$

$$= \left(\frac{4}{3}\pi r^3 \cdot \rho\right) c\Delta T \quad [\because m = V_{\text{sphere}}\,\rho]$$

Since, π, ρ, c and T are constants.

$\Rightarrow$ $Q \propto r^3$ or $\frac{Q_1}{Q_2} = \frac{r_1^3}{r_2^3}$

$$= \left(\frac{r_1}{r_2}\right)^3 = \left(\frac{1.5r_2}{r_2}\right)^3 = \frac{27}{8}$$

Hence, correct option is (d).

09 A piece of ice falls from a height h so that it melts completely. Only one-quarter of the heat produced is absorbed by the ice and all energy of ice gets converted into heat during its fall. The value of h is [Latent heat of ice is 3.4×10^5 J/kg and $g = 10$ N / kg] **[NEET 2016]**

(a) 544 km (b) 136 km
(c) 68 km (d) 34 km

Ans. *(b)*

According to question as conservation of energy, energy gained by the ice during its fall from height h is given by

$$E = mgh$$

As given, only one quarter of its energy is absorbed by the ice.

So, $\frac{mgh}{4} = mL_f \Rightarrow h = \frac{mL_f \times 4}{mg}$

$$= \frac{L_f \times 4}{g} = \frac{3.4 \times 10^5 \times 4}{10}$$

$$= 13.6 \times 10^4 = 136000 \text{ m} = 136 \text{ km}$$

10 Two identical bodies are made of a material for which the heat capacity increases with temperature. One of these is at 100°C, while the other one is at 0°C. If the two bodies are brought into contact, then assuming no heat loss, the final common temperature is **[NEET 2016]**

(a) 50°C
(b) more than 50°C
(c) less than 50°C but greater than 0°C
(d) 0°C

Ans. *(b)*

Heat lost by Ist body = heat gained by IInd body. Body at 100°C temperature has greater heat capacity than body at 0°C so final temperature will be closer to 100°C. So, $T_c > 50°C$.

11 Steam at 100°C is passed into 20 g of water at 10°C. When water acquires a temperature of 80°C, the mass of water present will be [Take specific heat of water = 1 cal $g^{-1}°C^{-1}$ and latent heat of steam = 540 cal g^{-1}] **[CBSE AIPMT 2014]**

(a) 24 g (b) 31.5 g (c) 42.5 g (d) 22.5 g

Ans. *(d)*

Concept Apply principle of calorimetry.

According to principle of calorimetry

Heat lost by steam = Heat gained by water

Let m' be the amount of steam that converts into water.

$$m' \times L + m' s\,\Delta T = ms\,\Delta t$$

$$\left[\begin{array}{l} s = \text{Specific heat of water} \\ L = \text{Latent heat of water} \end{array}\right]$$

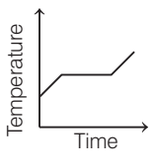
$m' \times 540 + m' \times 1 \times (100 - 80) = 20 \times 1 \times (80 - 10)$

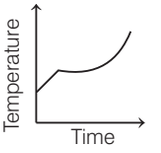
$$m' = \frac{20 \times 70}{560} = 2.5 \text{ g}$$

Now, net mass of water

$= 20 + 2.5 = 22.5$ g

12 Liquid oxygen at 50 K is heated to 300 K at constant pressure of 1 atm. The rate of heating is constant. Which one of the following graphs represents the variation of temperature with time? **[CBSE AIPMT 2012]**

(a)


(b)


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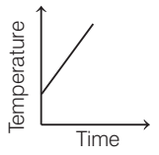
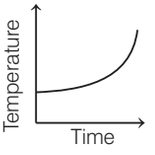
(c)


(d)


Ans. ***(a)***

Graph (a) shows the variation of temperature with time. At first temperature will increase then there will be state change from liquid to gas.

13 When 1 kg of ice at 0°C melts to water at 0°C, the resulting change in its entropy, taking latent heat of ice to be 80 cal/°C, is **[CBSE AIPMT 2011]**

(a) 8×10^4 cal/K (b) 80 cal/K
(c) 293 cal/K (d) 273 cal/K

Ans. ***(c)***

Change in entropy is given by

$$\Delta S = \frac{ml}{T} = \frac{1000 \times 80}{273} = 293 \text{ cal K}^{-1}$$

14 If 1 g of steam is mixed with 1 g of ice, then the resultant temperature of the mixture is **[CBSE AIPMT 1999]**

(a) 270°C (b) 230°C (c) 100°C (d) 50°C

Ans. ***(c)***

Heat required by 1g ice at 0°C to melt into 1g water at 0°C,

$Q_1 = mL$ (L = latent heat of fusion)
$= 1 \times 80 = 80$ cal (L = 80 cal/g)

Heat required by 1g of water at 0°C to boil at 100°C,

$Q_2 = mc\Delta\theta$
(c = specific heat of water)
$= 1 \times 1(100 - 0)$ (c = 1 cal/g°C)
$= 100$ cal

Thus, total heat required by 1g of ice to reach a temperature of 100°C,

$Q = Q_1 + Q_2 = 80 + 100 = 180$ cal

Heat available with 1 g of steam to condense into 1g of water at 100°C,

$Q' = mL'$ (L' = latent heat of vaporisation)

$= 1 \times 536$ cal (L' = 536 cal/g)
$= 536$ cal

Obviously, the whole steam will not be condensed and ice will attain temperature of 100°C. Thus, the temperature of mixture is 100°C.

15 Thermal capacity of 40 g of aluminium (s = 0.2 cal/g-K) is **[CBSE AIPMT 1990]**

(a) 168 J/°C (b) 672 J/°C
(c) 840 J/°C (d) 33.6 J/°C

Ans. ***(d)***

Thermal capacity of a body is defined as the amount of heat required to raise the temperature of the (whole) body through 1°C or 1 K.

Amount of heat energy required (ΔQ) to raise the temperature of mass m of a body through temperature range (ΔT) is

$$\Delta Q = sm(\Delta T)$$

where, s is specific heat of the body,

when ΔT = 1K, ΔQ = thermal capacity

$\therefore$ Thermal capacity $= s \times m \times 1$
$= ms$

Here, m = 40 g, s = 0.2 cal/g K

$\therefore$ Thermal capacity $= 40 \times 0.2 = 8$ cal/°C
$= 4.2 \times 8$ J/°C = 33.6 J/°C

16 Two containers A and B are partly filled with water and closed. The volume of A is twice that of B and it contains half the amount of water in B. If both are at the same temperature, the water vapour in the containers will have pressure in the ratio of **[CBSE AIPMT 1988]**

(a) 1 : 2 (b) 1 : 1 (c) 2 : 1 (d) 4 : 1

Ans. ***(b)***

Vapour pressure of a substance is independent of amount of substance. It depends only on temperature. So they have ratio of 1 : 1.

17 10 g of ice cubes at 0°C are released in a tumbler (water equivalent 55 g) at 40°C. Assuming that negligible heat is taken from the surroundings, the temperature of water in the tumbler becomes nearly (L = 80 cal/g) **[CBSE AIPMT 1988]**

(a) 31°C (b) 22°C (c) 19°C (d) 15°C

Ans. ***(b)***

Let θ be the temperature when thermal equilibrium has reached.

Heat gained by ice to be converted to water at θ°C

$= mL + m \times s \times (\theta - 0)$
$= 10 \times 80 + 10 \times 1 \times \theta$

Heat lost by tumbler and its contents
$= 55 \times (40 - \theta)$

Using principle of calorimetry that heat gained = heat lost

$$10 \times 80 + 10 \times 1 \times \theta = 55 \times (40 - \theta)$$
$$65\theta = 2200 - 800 = 1400$$
$$\theta = \frac{1400}{65} \approx 21.5\,°\text{C} \approx 22\,°\text{C}$$

TOPIC 3
Heat Transfer

18 A cup of coffee cools from 90°C to 80°C in t minutes, when the room temperature is 20°C. The time taken by a similar cup of coffee to cool from 80°C to 60°C at a room temperature same at 20°C, is **[NEET 2021]**

(a) $\frac{13}{10}t$ (b) $\frac{13}{5}t$
(c) $\frac{10}{13}t$ (d) $\frac{5}{13}t$

Ans. ***(b)***

In first conditions;

Given, the initial temperature of the cup of coffee, $T_i = 90°\text{C}$

The final temperature of the cup of coffee, $T_f = 80°\text{C}$

The time taken to drop the temperature 90°C to 80°C is t.

The temperature of the surrounding, $T_0 = 20°\text{C}$

Using the Newton's law of cooling,

$$\text{rate of cooling} = \frac{dT}{dt} = K\left[\frac{T_i + T_f}{2} - T_0\right]$$

Substituting the values in the above equation, we get

$$\frac{90 - 80}{t} = K\left[\frac{90 + 80}{2} - 20\right]$$
$$\Rightarrow \quad \frac{10}{t} = K[65] \quad \Rightarrow \quad K = \frac{2}{13t}$$

In second conditions;

The initial temperature of the cup of coffee, $T_i' = 80°\text{C}$

The final temperature of the cup of coffee, $T_f' = 60°\text{C}$.

Using the Newton's law of cooling,

$$\text{rate of cooling} = \frac{dT}{dt} = K\left[\frac{T'_i + T'_f}{2} - T_0\right]$$

Substituting the values in the above equation, we get

$$\frac{80 - 60}{t_1} = \frac{2}{13t}\left[\frac{60 + 80}{2} - 20\right]$$
$$\frac{20}{t_1} = \frac{2}{13t}[50] \quad \Rightarrow \quad t_1 = \frac{13}{5}t$$

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19 Three stars *A*,*B*,*C* have surface temperatures T_A, T_B, T_C, respectively. Star *A* appears bluish, start *B* appears reddish and star *C* yellowish. Hence **[NEET (Oct.) 2020]**

(a) $T_A > T_B > T_C$ (b) $T_B > T_C > T_A$
(c) $T_C > T_B > T_A$ (d) $T_A > T_C > T_B$

Ans. *(d)*

According to Wein's displacement law,

$$\lambda = \frac{b}{T}$$

i.e., $\lambda \propto \frac{1}{T}$ ... (i)

We know that,

$$\lambda_{bluish} < \lambda_{yellowish} < \lambda_{reddish}$$

Hence, using Eq. (i), we have

$$T_A > T_C > T_B$$

20 An object kept in a large room having air temperature of 25°C takes 12 minutes to cool from 80°C to 70°C.

The time taken to cool for the same object from 70°C to 60°C would be nearly **[NEET (Odisha) 2019]**

(a) 10 min (b) 12 min
(c) 20 min (d) 15 min

Ans. *(d)*

Key Idea From Newton's law of cooling, the time taken (t) by a body to cool from T_1 to T_2 when placed in a medium of temperature T_0 can be calculated from relation

$$\frac{T_1 - T_2}{t} = \frac{1}{K}\left(\frac{T_1 + T_2}{2} - T_0\right)$$

When the object cool from 80°C to 70°C in 12 minutes, then from Newton's law of cooling,

$$\frac{80 - 70}{12} = \frac{1}{K}\left(\frac{80 + 70}{2} - 25\right) [\because T_0 = 25°\,C]$$

$$\frac{5}{6} = \frac{1}{K}50 \quad ...(i)$$

Similarly, when object cool from 70°C to 60°C we get

$$\frac{70 - 60}{t} = \frac{1}{K}\left(\frac{70 + 60}{2} - 25\right)$$

$$\frac{10}{t} = \frac{1}{K}40 \quad ...(ii)$$

Divide Eq. (i) and (ii), we get

$$\frac{5}{6} \times \frac{t}{10} = \frac{50}{40}$$

$$\Rightarrow \quad t = \frac{5}{4} \times 12 = 15 \text{ minutes}$$

21 A deep rectangular pond of surface area A, containing water (density = ρ, specific heat capacity = s), is located in a region where the outside air temperature is a steady value at the −26°C. The thickness of the frozen ice layer in this pond, at a certain instant is *x*.

Taking the thermal conductivity of ice as K, and its specific latent heat of fusion as L, the rate of increase of the thickness of ice layer, at this instant would be given by **[NEET (Odisha) 2019]**

(a) 26K/ρ *r*(L–4s) (b) 26K/(ρx^2 − *L*)
(c) 26K/(ρ*xL*) (d) 26K/ρ*r*(*L* + 4s)

Ans. *(c)*

Key Idea If area of cross-section of a surface is not uniform or if the steady state condition is not reached, the heat flow equation can be applied to a thin layer of material perpendicular to direction of heat flow.

The rate of heat flow by conduction for growth of ice is given by,

$$\frac{d\theta}{dt} = \frac{KA(\theta_0 - \theta_1)]}{x}$$

where, $d\theta = \rho A dx L$, $\theta_0 = 0$ and $\theta_1 = -\theta$

Given, $\theta_0 = 0°\,C, \theta_1 = -26°\,C$

The rate of increase of thickness can be calculated from Eq.

$$\frac{d\theta}{dt} = \frac{KA(\theta_0 - \theta_1)}{x}$$

$$\Rightarrow \quad \frac{\rho A dx L}{dt} = \frac{KA(\theta_0 - \theta_1)}{x}$$

$$\Rightarrow \quad \frac{dx}{dt} = \frac{KA(\theta_0 - \theta_1)}{\rho A x L}$$

$$= \frac{K[0 - (-26)]}{\rho x L} = \frac{26K}{\rho x L}$$

22 The power radiated by a black body is *P* and it radiates maximum energy at wavelength, λ_0. If the temperature of the black body is now changed, so that it radiates maximum energy at wavelength $\frac{3}{4}\lambda_0$, the power radiated by it becomes *nP*. The value of *n* is **[NEET 2018]**

(a) $\frac{256}{81}$ (b) $\frac{4}{3}$
(c) $\frac{3}{4}$ (d) $\frac{81}{256}$

Ans. *(a)*

According to Wien's law,

$$\lambda_{max} \propto \frac{1}{T}$$

i.e. $\lambda_{max} T$ = constant

where, λ_{max} is the maximum wavelength of the radiation emitted at temperature *T*.

$$\therefore \quad \lambda_{max_1} T_1 = \lambda_{max_2} T_2$$

or $\frac{T_1}{T_2} = \frac{\lambda_{max_2}}{\lambda_{max_1}}$ ...(i)

Here, $\lambda_{max_1} = \lambda_0$ and $\lambda_{max_2} = \frac{3}{4}\lambda_0$

Substituting the above values in Eq. (i), we get

$$\frac{T_1}{T_2} = \frac{\frac{3}{4}\lambda_0}{\lambda_0} = \frac{3}{4}$$

or $\frac{T_1}{T_2} = \frac{3}{4}$ ...(ii)

As we know that, from Stefan's law, the power radiated by a body at temperature *T* is given as

$$P = \sigma A e T^4$$

i.e. $P \propto T^4$

($\because$ the quantity σAe is constant for a body)

$$\Rightarrow \quad \frac{P_1}{P_2} = \frac{T_1^4}{T_2^4} = \left(\frac{T_1}{T_2}\right)^4$$

From Eq. (i), we get

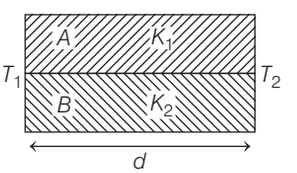
$$\frac{P_1}{P_2} = \left(\frac{3}{4}\right)^4 = \frac{81}{256}$$

Given, $P_1 = P$ and $P_2 = nP$

$$\Rightarrow \quad \frac{P_1}{P_2} = \frac{P}{nP} = \frac{81}{256}$$

or $n = \frac{256}{81}$

23 Two rods *A* and *B* of different materials are welded together as shown in figure. Their thermal conductivities are K_1 and K_2. The thermal conductivity of the composite rod will be **[NEET 2017]**



(a) $\frac{K_1 + K_2}{2}$ (b) $\frac{3(K_1 + K_2)}{2}$
(c) $K_1 + K_2$ (d) $2(K_1 + K_2)$

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Ans. *(a)*

In parallel arrangement of n rods

Equivalent thermal conductivity is given by

$$K_{eq} = \frac{K_1A_1 + K_2A_2 + \ldots + K_nA_n}{A_1 + A_2 + \ldots + A_n}$$

If rods are of same area, then

$$K_{eq} = \frac{K_1 + K_2 + \ldots + K_n}{n}$$

Now, in the question, it is not given that rods are of same area. But we can judge that from given diagram.

$\therefore$ Equivalent thermal conductivity of the system of two rods

$$\Rightarrow \quad K_{eq} = \frac{K_1 + K_2}{2}$$

24 A spherical black body with a radius of 12 cm radiates 450 watt power at 500 K. If the radius were halved and the temperature doubled, the power radiated in watt would be **[NEET 2017]**

(a) 225 (b) 450
(c) 1000 (d) 1800

Ans. *(d)*

Radiated power of a black body,

$$P = \sigma AT^4$$

where, A = surface area of the body

T = temperature of the body

and σ = Stefan's constant

When radius of the sphere is halved, new area,

$$A' = \frac{A}{4}$$

$\therefore$ Power radiated,

$$P' = \sigma\left(\frac{A}{4}\right)(2T)^4 = \frac{16}{4}\cdot(\sigma AT^4)$$

$$= 4P = 4 \times 450 = 1800 \text{ watts}$$

25 A black body is at a temperature of 5760 K. The energy of radiation emitted by the body at wavelength 250 nm is U_1, at wavelength 500 nm is U_2 and that at 1000 nm is U_3. Wien's constant, $b = 2.88 \times 10^6$ nmK. Which of the following is correct ? **[NEET 2016]**

(a) $U_3 = 0$ (b) $U_1 > U_2$
(c) $U_2 > U_1$ (d) $U_1 = 0$

Ans. *(c)*

Given, temperature, $T_1 = 5760$ K

Since, it is given that energy of radiation emitted by the body at wavelength 250 nm in U_1, at wavelength 500 nm is U_2 and that at 1000 nm is U_3.

$\because$ According to Wien's law, we get

$$\lambda_m T = b$$

where, b = Wien's constant = 2.88×10^6 nmK

$$\Rightarrow \quad \lambda_m = \frac{b}{T}$$

$$\Rightarrow \quad \lambda_m = \frac{2.88 \times 10^6 \text{ nmK}}{5760 \text{ K}}$$

$$\Rightarrow \quad \lambda_m = 500 \text{ nm}$$

$\because \lambda_m$ = wavelength corresponding to maximum energy, so, $U_2 > U_1$.

26 A body cools from a temperature $3T$ to $2T$ in 10 minutes. The room temperature is T. Assume that Newton's law of cooling is applicable. The temperature of the body at the end of next 10 minutes will be **[NEET 2016]**

(a) $\frac{7}{4}T$ (b) $\frac{3}{2}T$ (c) $\frac{4}{3}T$ (d) T

Ans. *(b)*

According to Newton's law of cooling,

$$\Delta T = \Delta T_0\, e^{-\lambda t}$$

$$\Rightarrow \quad 3T - 2T = (3T - T)\, e^{-\lambda \times 10} \quad \ldots(i)$$

Again for next 10 minutes

$$T' - T = (2T) \times e^{-\lambda (20)} \quad \ldots(ii)$$

From Eqs. (i) and (ii), we get

$$T' - T = (2T)(e^{-\lambda \times 10})^2 = (2T)\left(\frac{1}{2}\right)^2$$

$$= \frac{T}{2}$$

$$\therefore \quad T' = T + \frac{T}{2} = \frac{3T}{2}$$

27 The two ends of a metal rod are maintained at temperatures 100°C and 110°C. The rate of heat flow in the rod is found to be 4.0 J/s. If the ends are maintained at temperatures 200°C and 210°C, the rate of heat flow will be **[CBSE AIPMT 2015]**

(a) 44.0 J/s (b) 16.8 J/s
(c) 8.0 J/s (d) 4.0 J/s

Ans. *(d)*

Here, $\Delta T_1 = 110 - 100 = 10^\circ$ C

$\frac{dQ_1}{dt} = 4$ J/s $\Rightarrow$ $\Delta T_2 = 210 - 200 = 10^\circ$ C

$\frac{dQ_2}{dt} = ?$

As the rate of heat flow is directly proportional to the temperature difference and the temperature difference in both the cases is same i.e. 10ºC. So, the same rate of heat will flow in the second case.

Hence, $\frac{dQ_2}{dt} = 4$ J/s

28 Certain quantity of water cools from 70°C to 60°C in the first 5 min and to 54°C in the next 5 min. The temperature of the surroundings is **[CBSE AIPMT 2014]**

(a) 45°C (b) 20°C
(c) 42°C (d) 10°C

Ans. *(a)*

Concept Apply Newton's law of cooling.

Let the temperature of the surrounding be t°C.

For first case,

$$\frac{(70 - 60)}{5 \text{ min}} = K\,(65^\circ\text{C} - t^\circ\text{C})$$

(65° is average of 70°C and 60°C)

$$\frac{10}{5\text{min}} = K\,(65^\circ\text{C} - t^\circ\text{C}) \quad \ldots(i)$$

For second case,

$$\frac{(60 - 54)}{5\text{min}} = K\,(57 - t) \quad \ldots(ii)$$

(57°C is average of 60°C and 54°C)

From Eqs. (i) and (ii),

$$\frac{10}{6} = \frac{(65 - t)}{(57 - t)}$$

So, $t = 45^\circ$ C

29 A piece of iron is heated in a flame. If first becomes dull red then becomes reddish yellow and finally turns to white hot. The correct explanation for the above observation is possible by using **[NEET 2013]**

(a) Stefan's law
(b) Wien's displacement law
(c) Kirchhoff's law
(d) Newton's law of cooling

Ans. *(b)*

Equation of Wien's displacement law is given by $\lambda_m T$ = constant

30 If the radius of a star is R and it acts as a black body, what would be the temperature of the star, in which the rate of energy production is Q? **[CBSE AIPMT 2012]**

(σ stands for Stefan's constant.)

(a) $Q/4\pi R^2\sigma$ (b) $(Q/4\pi R^2\sigma)^{-1/2}$
(c) $(4\pi R^2 Q/\sigma)^{1/4}$ (d) $(Q/4\pi R^2\sigma)^{1/4}$

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Ans. *(d)*

From Stefan' law,

$$E = \sigma T^4$$

So, the rate of energy production

$$Q = E \times A$$

$$Q = \sigma T^4 \times 4\pi R^2$$

Temperature of star

$$T = \left(\frac{Q}{4\pi R^2 \sigma}\right)^{1/4}$$

31 A cylindrical metallic rod in thermal contact with two reservoirs of heat at its two ends conducts an amount of heat Q in time t. The metallic rod is melted and the material is formed into a rod of half the radius of the original rod. What is the amount of heat conducted by the new rod when placed in thermal contact with the two reservoirs in time t? **[CBSE AIPMT 2010]**

(a) $Q/4$ (b) $Q/16$ (c) $2Q$ (d) $Q/2$

Ans. *(b)*

In steady state the amount of heat flowing from one face to the other face in time t is given by $Q = \frac{KA(\theta_1 - \theta_2)t}{l}$,

where K is coefficient of thermal conductivity of material of rod

$$\Rightarrow \quad \frac{Q}{t} \propto \frac{A}{l} \propto \frac{r^2}{l} \qquad ...(i)$$

As the metallic rod is melted and the material is formed into a rod of half the radius

$$V_1 = V_2$$

$$\pi r_1^2 l_1 = \pi r_2^2 l_2 \qquad \left[\because r_2 = \frac{r_1}{2}\right]$$

$$\Rightarrow \quad l_1 = \frac{l_2}{4} \qquad ...(ii)$$

Now, from Eqs. (i) and (ii)

$$\frac{Q_1}{Q_2} = \frac{r_1^2}{l_1} \times \frac{l_2}{r_2^2} = \frac{r_1^2}{l_1} \times \frac{4l_1}{(r_1/2)^2}$$

$$\Rightarrow \quad Q_1 = 16\,Q_2 \;\Rightarrow\; Q_2 = \frac{Q_1}{16}$$

32 A black body at 227°C radiates heat at the rate of 7 cal $cm^{-2} s^{-1}$. At a temperature of 727°C, the rate of heat radiated in the same units will be **[CBSE AIPMT 2009]**

(a) 60 (b) 50 (c) 112 (d) 80

Ans. *(c)*

According to Stefan's law

$E = \sigma T^4$

σ = Stefan's constant

T = temperature

$$\frac{E_1}{E_2} = \left[\frac{T_1}{T_2}\right]^4 \Rightarrow E_2 = 7\left[\frac{273+727}{273+227}\right]^4$$

$$= \left[\frac{1000}{500}\right]^4 \times 7$$

$$= 112 \text{ cal-cm}^2 \text{s}^{-1}$$

33 The two ends of a rod of length L and a uniform cross-sectional area A are kept at two temperatures T_1 and T_2 ($T_1 > T_2$). The rate of heat transfer, $\frac{dQ}{dt}$, through the rod in a steady state is given by **[CBSE AIPMT 2009]**

(a) $\frac{dQ}{dt} = \frac{KL(T_1 - T_2)}{A}$ (b) $\frac{dQ}{dt} = \frac{K(T_1 - T_2)}{LA}$

(c) $\frac{dQ}{dt} = KLA(T_1 - T_2)$ (d) $\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{L}$

Ans. *(d)*

For a rod of length L and area of cross-section A whose faces are maintained at temperatures T_1 and T_2 respectively. Then in steady state the rate of heat flowing from one face to the other face in time t is given by

$$\frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{L}$$

34 A black body is at 727°C. It emits energy at a rate which is proportional to **[CBSE AIPMT 2007]**

(a) $(727)^2$ (b) $(1000)^4$

(c) $(1000)^2$ (d) $(727)^4$

Ans. *(b)*

According to Stefan's law,

$$E \propto T^4 \quad \text{or} \quad E = \sigma T^4$$

where, σ is constant of proportionality and called Stefan's constant. Its value is

$$5.67 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$$

Here, $E \propto (727 + 273)^4 \Rightarrow E \propto (1000)^4$

35 Assuming the sun to have a spherical outer surface of radius r, radiating like a black body at temperature t°C, the power received by a unit surface, (normal to the incident rays) at a distance R from the centre of the sun is where, σ is the Stefan's constant. **[CBSE AIPMT 2007]**

(a) $\frac{4\pi r^2 t^4}{R^2}$ (b) $\frac{r^2 \sigma (t+273)^4}{4\pi R^2}$

(c) $\frac{16\pi^2 r^2 \sigma t^4}{R^2}$ (d) $\frac{r^2 \sigma (t+273)^4}{R^2}$

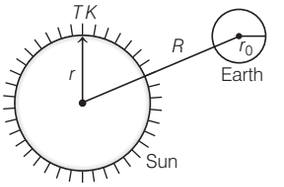
Ans. *(d)*

From Stefan's law, the rate at which energy is radiated by sun at its surface is

$$P = \sigma \times 4\pi r^2 T^4$$

[Sun is a perfectly black body as it emits radiations of all wavelengths and so for it $e = 1$]

The intensity of this power at the earth's surface (under the assumption $R >> r_0$) is



$$I = \frac{P}{4\pi R^2} = \frac{\sigma \times 4\pi r^2 T^4}{4\pi R^2}$$

$$= \frac{\sigma r^2 T^4}{R^2} = \frac{\sigma r^2 (t+273)^4}{R^2}$$

36 A black body at 1227°C emits radiations with maximum intensity at a wavelength of 5000 Å. If the temperature of the body is increased by 1000°C, the maximum intensity will be observed at **[CBSE AIPMT 2006]**

(a) 4000 Å (b) 5000 Å

(c) 6000 Å (d) 3000 Å

Ans. *(d)*

According to Wien's law

$\lambda_m T$ = constant (say b)

where, λ_m is wavelength corresponding to maximum intensity of radiation and T is temperatures of the body in kelvin. So for two different cases i.e. at two different temperature of body

$$\therefore \quad \frac{\lambda'_m}{\lambda_m} = \frac{T}{T'}$$

Given, $T = 1227 + 273 = 1500$ K,

$T' = 1227 + 1000 + 273$

$= 2500$ K

$\lambda_m = 5000$ Å

Hence, $\lambda'_m = \frac{1500}{2500} \times 5000 = 3000$ Å

37 Which of the following circular rods, (given radius r and length l) each made of the same material and whose ends are maintained at the same temperature will conduct most heat ? **[CBSE AIPMT 2005]**

(a) $r = 2r_0; l = 2l_0$ (b) $r = 2r_0; l = l_0$

(c) $r = r_0; l = l_0$ (d) $r = r_0; l = 2l_0$

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Ans. *(b)*

As from law of heat transfer through conduction

$$H = \frac{\Delta Q}{\Delta t} = KA\left(\frac{T_1 - T_2}{l}\right)$$

$$\Rightarrow \quad H \propto \frac{r^2}{l} \qquad \ldots(i)$$

(a) When $r = 2r_0; l = 2l_0$

$$H \propto \frac{(2r_0)^2}{2l_0} \Rightarrow H \propto \frac{2r_0^2}{l_0}$$

(b) When $r = 2r_0; l = l_0$

$$H \propto \frac{(2r_0)^2}{l_0} \Rightarrow H \propto \frac{4r_0^2}{l_0}$$

(c) When $r = r_0; l = l_0 \Rightarrow H \propto \frac{r_0^2}{l_0}$

(d) When $r = r_0; l = 2l_0 \Rightarrow H \propto \frac{r_0^2}{2l_0}$

It is obvious that heat conduction will be more in case (b).

38 If λ_m denotes the wavelength at which the radiative emission from a black body at a temperature T K is maximum, then **[CBSE AIPMT 2004]**

(a) $\lambda_m \propto T^4$

(b) λ_m is independent of T

(c) $\lambda_m \propto T$

(d) $\lambda_m \propto T^{-1}$

Ans. *(d)*

According to Wien's displacement law, the wavelength (λ_m) of maximum intensity of emission of black body radiation is inversely proportional to absolute temperature (T) of the black body.

i.e. $\lambda_m T = \text{constant}$

or $\lambda_m = \frac{\text{constant}}{T}$

or $\lambda_m \propto \frac{1}{T}$ or $\lambda_m \propto T^{-1}$

39 We consider the radiation emitted by the human body. Which of the following statements is true ? **[CBSE AIPMT 2003]**

(a) The radiation is emitted during the summers and absorbed during the winters

(b) The radiation emitted lies in the ultraviolet region and hence is not visible

(c) The radiation emitted is in the infrared region

(d) The radiation is emitted only during the day

Ans. *(c)*

The heat radiation emitted by the human body is the infrared radiation. Their wavelength is of the order of 7.9×10^{-7} m to 10^{-3} m which is of course the range of infrared region.

40 Consider a compound slab consisting of two different materials having equal thickneses and thermal conductivities K and $2K$, respectively. The equivalent thermal conductivity of the slab is **[CBSE AIPMT 2003]**

(a) $3K$ (b) $\frac{4}{3}K$ (c) $\frac{2}{3}K$ (d) $\sqrt{2}K$

Ans. *(b)*

The quantity of heat flowing across a slab in time t,

$$Q = \frac{KA\Delta\theta}{l}$$

K = thermal conductivity

ΔQ = change in temperature

A = area of slab

l = thickness

For same heat flow through each slab and (composite slab), we have

$$\frac{K_1 A(\Delta\theta_1)}{l} = \frac{K_2 A(\Delta\theta_2)}{l} = \frac{K' A(\Delta\theta_1 + \Delta\theta_2)}{2l}$$

or $K_1\Delta\theta_1 = K_2\Delta\theta_2 = \frac{K'}{2}(\Delta\theta_1 + \Delta\theta_2) = C$ (say)

So, $\Delta\theta_1 = \frac{C}{K_1}, \Delta\theta_2 = \frac{C}{K_2}$

and $(\Delta\theta_1 + \Delta\theta_2) = \frac{2C}{K'}$

or $\frac{C}{K_1} + \frac{C}{K_2} = \frac{2C}{K'}$

or $C\left(\frac{K_1 + K_2}{K_1 K_2}\right) = \frac{2C}{K'}$

$\therefore \quad K' = \frac{2K_1 K_2}{K_1 + K_2}$

Given, $K_1 = K, K_2 = 2K$

So, $K' = \frac{2K \times 2K}{K + 2K} = \frac{4}{3}K$

41 For a black body at temperature 727°C, its radiating power is 60 W and temperature of surrounding is 227°C. If the temperature of the black body is changed to 1227°C, then its radiating power will be **[CBSE AIPMT 2002]**

(a) 120 W (b) 240 W

(c) 304 W (d) 320 W

Ans. *(d)*

Boltzmann corrected Stefan's law and stated that the amount of radiations emitted by the body, not only depends upon the temperature of the body but also on the temperature of the surrounding. The radiated power by the body is given by

$$P = \sigma(T^4 - T_0^4) \qquad \ldots(i)$$

where T_0 is the absolute temperature of the surrounding and T is the temperature of body.

So for two different cases ratio of radiation power is given by

$$\therefore \quad \frac{P_2}{P_1} = \left(\frac{T_2^4 - T_0^4}{T_1^4 - T_0^4}\right) \qquad \ldots(ii)$$

Here, $P_1 = 60$ W, $T_1 = 727°C = 1000$ K

$T_0 = 227°C = 500$ K,

$T_2 = 1227°C = 1500$ K

Substituting in Eq. (ii), we get

$$P_2 = \frac{(1500)^4 - (500)^4}{(1000)^4 - (500)^4} \times 60$$

$$= \frac{(500)^4}{(500)^4} \times \left[\frac{3^4 - 1}{2^4 - 1}\right] \times 60$$

$$= \frac{80}{15} \times 60 = 320 \text{ W}$$

42 Consider two rods of same length and different specific heats (s_1, s_2), thermal conductivities (K_1, K_2) and areas of cross-section (A_1, A_2) and both having temperatures (T_1, T_2) at their ends. If their rate of loss of heat due to conduction are equal, then **[CBSE AIPMT 2002]**

(a) $K_1A_1 = K_2A_2$ (b) $\frac{K_1A_1}{s_1} = \frac{K_2A_2}{s_2}$

(c) $K_2A_1 = K_1A_2$ (d) $\frac{K_2A_1}{s_2} = \frac{K_1A_2}{s_1}$

Ans. *(a)*

Rate of loss of heat by conduction is,

$$H = \frac{\Delta Q}{\Delta t} = K\,A\left(\frac{T_1 - T_2}{l}\right)$$

All the symbols have their usual meaning.

For first rod, $H_1 = K_1A_1\left(\frac{T_1 - T_2}{l_1}\right)$

For second rod, $H_2 = K_2A_2\left(\frac{T_1 - T_2}{l_2}\right)$

but $l_1 = l_2$ i.e. of same length

and $H_1 = H_2$ i.e. same rate of loss of heat through conduction. So, we have

$$K_1A_1(T_1 - T_2) = K_2A_2(T_1 - T_2)$$

or $K_1A_1 = K_2A_2$

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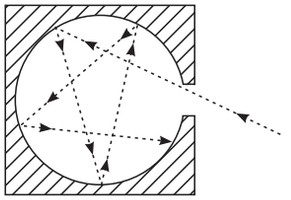
43 Wien's displacement law expresses relation between
[CBSE AIPMT 2002]
(a) wavelength corresponding to maximum energy and absolute temperature
(b) radiated energy and wavelength
(c) emissive power and temperature
(d) colour of light and temperature

Ans. *(a)*
According to Wien's displacement law, the quantity of energy radiated out by a body is not uniformly distributed over all the wavelengths emitted by it. It is maximum for a particular wavelength (λ), which is different at different temperatures. As the temperature is increased, the value of the wavelength which carries maximum energy is decreased.
The statement of this law is as follows
"The wavelength corresponding to maximum energy is inversely proportional to the absolute temperature of the body."
i.e. $\lambda_m \propto \frac{1}{T}$
or $\lambda_m T = \text{constant}$

44 Which of the following is close to an ideal black body ?
[CBSE AIPMT 2002]
(a) Black lamp
(b) Cavity maintained at constant temperature
(c) Platinum black
(d) A lamp of charcoal heated to high temperature

Ans. *(b)*
Materials like black velvet or lamp black come close to ideal black bodies, but the best practical realization of an ideal black body is a small hole leading into a cavity maintained at constant temperature as this absorbs 98% of the radiation incident on them. Cavity approxi- mating an ideal black body is shown in the figure. Radiation entering the cavity has little chance of leaving before it is completely absorbed.



45 Rate of heat flow through a cylindrical rod is H_1. Temperatures of ends of rod are T_1 and T_2. If all the dimensions of rod become double and temperature difference remains same and rate of heat flow becomes H_2. Then,
[CBSE AIPMT 2001]
(a) $H_2 = 2H_1$ (b) $H_2 = \frac{H_1}{2}$
(c) $H_2 = \frac{H_1}{4}$ (d) $H_2 = 4H_1$

Ans. *(a)*
Rate of heat flow w.r.t. time
$$\frac{H_2}{H_1} = \frac{I_2}{I_1} = \frac{2I_1}{I_1}$$
K = Thermal conductivity
A = Area of body
l = Thickness or $H \propto \frac{A}{l}$
Since, dimensions of area $(A) = [L^2]$
Dimensions of length $(l) = [L]$
$\therefore \quad H \propto l$
or $\frac{H_2}{H_1} = \frac{l_2}{l_1} = \frac{2l_1}{l_1} \quad (\because l_2 = 2l_1)$
or $H_2 = 2H_1$

46 The wavelength corresponding to maximum intensity of radiation emitted by a source at temperature 2000 K is λ, then what is the wavelength corresponding to maximum intensity of radiation at temperature 3000 K?
[CBSE AIPMT 2001]
(a) $\frac{2}{3}\lambda$ (b) $\frac{16}{81}\lambda$ (c) $\frac{81}{16}\lambda$ (d) $\frac{4}{3}\lambda$

Ans. *(a)*
Wien's displacement law is given by
$\lambda_m T = \text{constant}$
λ_m = maximum wavelength radiation
T = temperature of the body
So for two different cases, i.e. at two different temperatures
or $\lambda_1 T_1 = \lambda_2 T_2$
$$\lambda_2 = \lambda_1 \left(\frac{T_1}{T_2}\right)$$
Given, $T_1 = 2000\ \text{K}, T_2 = 3000\ \text{K}, \quad \lambda_1 = \lambda$
$\therefore \quad \lambda_2 = \lambda \times \frac{2000}{3000} = \frac{2}{3}\lambda$

47 Which one of the following processes depends on gravity ?
[CBSE AIPMT 2000]
(a) Conduction (b) Convection
(c) Radiation (d) None of these

Ans. *(b)*
(a) Conduction is the process of transmission of heat in a body from the hotter part to the colder part without any bodily movement of constituent atoms or molecules of the body.
(b) In convection, the heated lighter particles move upward and colder heavier particles move downward to their place. This depends on weight and hence, on gravity.
(c) Radiation is the process of transmission of heat from one body to another body through electromagnetic waves even through vacuum, irrespective of their temperatures.
Hence, choice (b) is correct.

48 The radiant energy from the sun, incident normally at the surface of earth is 20 kcal/m^2 min. What would have been the radiant energy, incident normally on the earth, if the sun had a temperature, twice of the present one ?
[CBSE AIPMT 1998]
(a) 160 kcal/m^2 min (b) 40 kcal/m^2 min
(c) 320 kcal/m^2 min (d) 80 kcal/m^2 min

Ans. *(c)*
Concept Apply Stefan's law
According to Stefan's law, the rate at which an object radiates energy is proportional to the fourth power of its absolute temperature, i.e.
$$E = \sigma T^4 \quad \text{or} \quad E \propto T^4$$
(σ = Stefan's constant)
so for two different cases, $\frac{E_1}{E_2} = \left(\frac{T_1}{T_2}\right)^4$
Given, $T_1 = T, T_2 = 2T, E_1 = 20\ \text{kcal/m}^2\ \text{min}$
$\therefore \quad \frac{20}{E_2} = \left(\frac{T}{2T}\right)^4 \quad \text{or} \quad \frac{20}{E_2} = \frac{1}{16}$
$\therefore \quad E_2 = 20 \times 16 = 320\ \text{kcal/m}^2\ \text{min}$

49 A black body is at temperature of 500 K. It emits energy at rate which is proportional to **[CBSE AIPMT 1997]**
(a) $(500)^4$ (b) $(500)^3$ (c) $(500)^2$ (d) 500

Ans. *(a)*
According to Stefan's law, energy emitted
$$E \propto T^4$$
$$E = \sigma T^4$$
(σ = Stefan's constant)
$\therefore \quad E \propto (500)^4$

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50 A beaker full of hot water is kept in a room. If it cools from 80°C to 75°C in t_1 minutes, from 75°C to 70°C in t_2 minutes and from 70°C to 65°C to in t_3 minutes, then **[CBSE AIPMT 1995]**

(a) $t_1 = t_2 = t_3$ (b) $t_1 < t_2 = t_3$
(c) $t_1 < t_2 < t_3$ (d) $t_1 > t_2 > t_3$

Ans. *(c)*

By Newton's law of cooling, rate of fall of temperature ∝ average temperature excess. In each case average temperature excess decreases, so rate of fall of temperature decreases. Hence, $t_1 < t_2 < t_3$. Because more and more time is required to cool, if the average temperature goes Q in decreasing.

51 A body cools from 50°C to 49.9°C in 5 s. How long will it take to cool from 40°C to 39.9°C ? (Assume the temperature of surroundings to be 30.0°C and Newton's law of cooling to be valid) **[CBSE AIPMT 1994]**

(a) 2.5 s (b) 10 s
(c) 20 s (d) 5 s

Ans. *(b)*

According to Newton's law of cooling, the rate of loss of heat of a body is directly proportional to the difference in temperatures of the body and the surroundings, provided the difference in temperature is small, not more than 30°C.

∴Average rate of fall of temperature ∝ average temperature excess

i.e., $\frac{dT}{dt} \propto (T_t - T_s)$

$\Rightarrow \quad \frac{dT}{dt} = K(T_t - T_s)$

According to question for 1st and 2nd case,

$$\frac{50.1 - 49.9}{5} = k\left[\frac{50.1 + 49.9}{2} - 30\right] \quad ...(i)$$

$$\frac{40.1 - 39.9}{t'} = k\left[\frac{40.1 + 39.9}{2} - 30\right] \quad ...(ii)$$

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{2}{5} \times \frac{t'}{2} = \frac{20}{10} \Rightarrow t' = 10\,\text{s}$$

52 If the temperature of the sun is doubled, the rate of energy received on earth will be increased by a factor of **[CBSE AIPMT 1993]**

(a) 2 (b) 4
(c) 8 (d) 16

Ans. *(d)*

According to Stefan-Boltzmann law, amount of heat energy (E) radiated per second by unit area of a body is directly proportional to the fourth power of absolute temperature (T) of the body

i.e. $E \propto T^4$ or $E = \sigma T^4$

If T is doubled, E becomes $(2)^4$ times (i.e. 16 times).

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11

Thermodynamics

TOPIC 1
Zeroth and First Law of Thermodynamics

01 1g of water, of volume 1 cm^3 at 100°C is converted into steam at same temperature under normal atmospheric pressure=($\simeq 1\times10^5$ Pa). The volume of steam formed equals 1671 cm^3. If the specific latent heat of vaporisation of water is 2256 J/g, the change in internal energy is **[NEET (Odisha) 2019]**

(a) 2423 J (b) 2089 J
(c) 167 J (d) 2256 J

Ans. *(b)*

Given, mass of water, $m = 1$ g
Volume of 1 g of water $= 1\,cm^3 = 10^{-6}\ m^3$
Volume of 1 g of steam $= 1671\,cm^3$
$= 1671\times10^{-6}\ m^3$
Pressure, $p = 1\times10^5$ Pa
Latent heat of vaporization of water,
$L = 2256$ J/g
Change in volume,
$\Delta V = (1671-1)\times10^{-6}\ m^3$
$= 1670\times10^{-6}\ m^3$ ...(i)
Heat supplied,
$\Delta Q = mL = 1\times2256 = 2256$ J ...(ii)
As the steam expands, so the work done in expansion is
$\Delta W = p\Delta V$
$= 1\times10^5\times1670\times10^{-6}$ [from Eq. (i)]
$= 167$ J ...(iii)
According to first law of thermodynamics,
$\Delta Q = \Delta U + \Delta W$
$\Rightarrow\ \Delta U = \Delta Q - \Delta W$
$= 2256 - 167$ [from Eq. (ii) and (iii)]
$= 2089$ J

02 A sample of 0.1 g of water at 100°C and normal pressure ($1.013\times10^5\ Nm^{-2}$) requires 54 cal of heat energy to convert to steam at 100°C. If the volume of the steam produced is 167.1 cc, the change in internal energy of the sample, is **[NEET 2018]**

(a) 42.2 J (b) 208.7 J
(c) 104.3 J (d) 84.5 J

Ans. *(b)*

According to the question,
Heat spent during the conversion of sample of water at 100° C to steam is,
$\Delta Q = 54\,cal = 54\times4.18$ J
$= 225.72$ J
Normal pressure, $p = 1.013\times10^5\ Nm^{-2}$
Net work done during the conversion would be given as
$\Delta W = p\Delta V$
$= p[V_{steam} - V_{water}]$
Here, $V_{steam} = 167.1$ cc $= 167.1\times10^{-6}\ m^3$
$V_{water} = 0.1$ g $= 0.1$cc $= 0.1\times10^{-6}\ m^3$
$\therefore\ \Delta W = 1.013\times10^5\ [(167.1-0.1)\times10^{-6}]$
$= 1.013\times167\times10^{-1}$
$= 16.917$ J
Now, by the first law of thermodynamics,
$\Delta Q = \Delta U + \Delta W$
where, ΔU is the change in internal energy of the sample.
$\Rightarrow\ \Delta U = \Delta Q - \Delta W$
Substituting the values in the above equation, we get
$\Delta U = 225.72 - 16.917 = 208.7$ J

03 During an isothermal expansion, a confined ideal gas does –150 J of work against its surroundings. This implies that **[CBSE AIPMT 2011]**

(a) 300 J of heat has been added to the gas
(b) no heat is transferred because the process is isothermal
(c) 150 J of heat has been added to the gas
(d) 150 J of heat has been removed from the gas

Ans. *(c)*

Concept Apply first law of thermodynamics.
According to first law of thermodynamics
$\Delta U = \Delta Q + \Delta W$
For isothermal process, $\Delta U = 0$
So, $\Delta Q = -\Delta W$
Given, $\Delta W = -150$ J
So, $\Delta Q = +150$ J
When Q is positive, the heat is added to the gas.

04 If ΔU and ΔW represent the increase in internal energy and work done by the system respectively in a thermodynamical process, which of the following is true? **[CBSE AIPMT 2010]**

(a) $\Delta U = -\Delta W$, in an adiabatic process
(b) $\Delta U = \Delta W$, in an isothermal process
(c) $\Delta U = \Delta W$, in an adiabatic process
(d) $\Delta U = -\Delta W$, in an isothermal process

Ans. *(a)*

From first law of thermodynamics
$\Delta Q = \Delta U + \Delta W$
For adiabatic process, $\Delta Q = 0$
$\because\ \Delta Q = 0$
So, $\Delta U = -\Delta W$

05 The internal energy change in a system that has absorbed 2 kcal of heat and done 500 J of work is **[CBSE AIPMT 2009]**

(a) 8900 J (b) 6400 J
(c) 5400 J (d) 7900 J

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Ans. *(d)*

According to first law of thermodynamics

$$\Delta Q = U + W$$

or $\Delta U = Q - W$

ΔU = change in internal energy

Q = heat given to system

W = work done

$\therefore \quad \Delta U = 2 \times 4.2 \times 1000 - 500$

$= 8400 - 500 = 7900\ \text{J}$

06 If Q, E and W denote respectively the heat added, change in internal energy and the work done in a closed cycle process, then **[CBSE AIPMT 2008]**

(a) $W = 0$ (b) $Q = W = 0$

(c) $E = 0$ (d) $Q = 0$

Ans. *(c)*

For a cyclic process, $\Delta U = 0$ or $E = 0$

07 We consider a thermodynamic system. If ΔU represents the increase in its internal energy and W the work done by the system, which of the following statements is true ? **[CBSE AIPMT 1998]**

(a) $\Delta U = -W$ in an adiabatic process

(b) $\Delta U = W$ in an isothermal process

(c) $\Delta U = -W$ in an isothermal process

(d) $\Delta U = W$ in an adiabatic process

Ans. *(a)*

An isothermal process is a constant temperature process. In this process, T = constant or $\Delta T = 0$.

$\therefore \quad \Delta Q = \Delta U + \Delta W$

$\Rightarrow \quad \Delta Q = \Delta W \qquad (\Delta U = 0)$

$\Delta U = nC_v\ \Delta T = 0$

An adiabatic process is defined as one with no heat transfer into or out of a system. Therefore, $Q = 0$. From the first law of thermodynamics.

$$\Delta Q = \Delta U + \Delta W$$

or $\Delta U = -W \qquad [\Delta Q = 0]$

08 110 J of heat is added to a gaseous system, whose internal energy is 40 J, then the amount of external work done is **[CBSE AIPMT 1993]**

(a) 150 J (b) 70 J (c) 110 J (d) 40 J

Ans. *(b)*

Concept Apply first law of thermodynamics to calculate the required work done.

From first law of thermodynamics

$$\Delta Q = \Delta U + \Delta W$$

where, ΔQ = heat given

ΔU = change in internal energy

ΔW = work done

Here, $\Delta Q = 110$ J

$\Delta U = 40$ J

$\therefore \quad \Delta W = \Delta Q - \Delta U = 110 - 40 = 70$ J

09 First law of thermodynamics is a consequence of conservation of **[CBSE AIPMT 1988]**

(a) work (b) energy

(c) heat (d) All of these

Ans. *(b)*

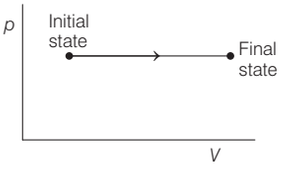
According to the first law of thermodynamics, when some quantity of heat (dQ) is supplied to a system capable of doing external work, then the quantity of heat absorbed by the system (dQ) is equal to the sum of the increase in the internal energy of the system (dU) due to rise in temperature and the external work done by the system (dW) in expansion,

i.e. $dQ = dU + dW$

This law, which is basically the law of conservation of energy applies to every process in nature.

TOPIC 2
Thermodynamic Process

10 The p-V diagram for an ideal gas in a piston cylinder assembly undergoing a thermodynamic process is shown in the figure. The process is **[NEET (Oct.) 2020]**

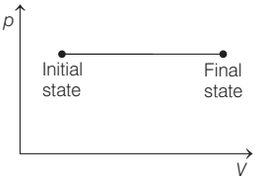


(a) adiabatic (b) isochoric

(c) isobaric (d) isothermal

Ans. *(c)*

pV-diagram for an ideal gas is given as



From the pV diagram, it is clear that pressure of ideal gas in the piston cylinder is constant during thermodynamic process. Hence, this process is isobaric.

11 Two cylinders A and B of equal capacity are connected to each other *via* a stop cock. A contains an ideal gas at standard temperature and pressure. B is completely evacuated. The entire system is thermally insulated. The stop cock is suddenly opened. The process is **[NEET (Sep.) 2020]**

(a) adiabatic (b) isochoric

(c) isobaric (d) isothermal

Ans. *(a)*

Since, the entire system is thermally insulated. Thus, their will be no transfer of heat between the system and the surrounding. Hence, when the stop cock is suddenly opened, a sudden process of expansion will takes place with no heat transfer. Thus, the given process will be adiabatic, as it is a process that occurs without transferring heat or mass between a thermodynamic system and its surroundings.

Hence, correct option is (a).

12 In which of the following processes, heat is neither absorbed nor released by a system? **[NEET (National) 2019]**

(a) Adiabatic

(b) Isobaric

(c) Isochoric

(d) Isothermal

Ans. *(a)*

In an adiabatic process, the system is completely insulated from the surroundings. Thus, heat is neither absorbed nor released by the system to the surroundings. So, $\Delta Q = 0$.

Sudden processes are adiabatic like bursting of cycle tyre, etc.

If the pressure of gas is kept constant, then the process is called isobaric, i.e. $\Delta p = 0$.

If the temperature of the system remains constant, then it is called isothermal process, i.e. $\Delta T = 0$.

If the volume of gas is constant in a system, then it is called isochoric process, i.e. $\Delta V = 0$.

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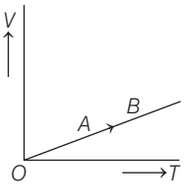
13 The volume (V) of a monoatomic gas varies with its temperature (T), as shown in the graph. The ratio of work done by the gas, to the heat absorbed by it, when it undergoes a change from state A to state B, is **[NEET 2018]**



(a) $\frac{1}{3}$ (b) $\frac{2}{3}$
(c) $\frac{2}{5}$ (d) $\frac{2}{7}$

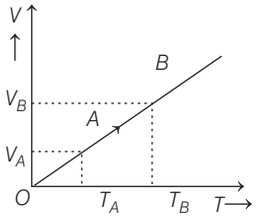
Ans. *(c)*

According to the given graph,

Volume (V) $\propto$ Temperature (T)

or $\frac{V}{T}$ = constant

Thus, the process is isobaric.



$\therefore$ Work done, $\Delta W = p\Delta V$

$= nR\Delta T = nR(T_B - T_A)$ ...(i)

Heat absorbed $\Delta Q = nC_p\Delta T$

$= nC_p(T_B - T_A)$ ...(ii)

As, $C_p = \frac{\gamma R}{\gamma - 1}$, $\left(\text{where, } \gamma = 1 + \frac{2}{f}\right)$

For a monoatomic gas, $f = 3$

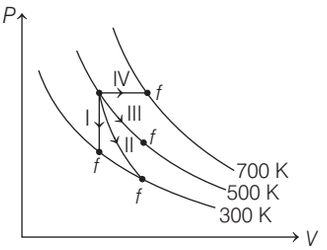
$\Rightarrow$ $C_p = \left(R + \frac{3}{2}R\right) = \frac{5}{2}R$

Substituting the value of C_p in Eq. (ii), we get

$$\Delta Q = n\left(\frac{5}{2}R\right)(T_B - T_A)$$

Hence, $\frac{\Delta W}{\Delta Q} = \frac{nR(T_B - T_A)}{n\left(\frac{5}{2}R\right)(T_B - T_A)} = \frac{2}{5}$

14 Thermodynamic processes are indicated in the following diagram **[NEET 2017]**



Match the following :

	Column-I		Column-II
P.	Process I	a.	Adiabatic
Q.	Process II	b.	Isobaric
R.	Process III	c.	Isochoric
S.	Process IV	d.	Isothermal

(a) P→ a, Q→ c, R→ d, S→ b
(b) P→ c, Q→ a, R→ d, S→ b
(c) P→ c, Q→ d, R→ b, S→ a
(d) P→ d, Q→ b, R→ a, S→ c

Ans. *(b)*

In isochoric process, the curve is parallel to y-axis because volume is constant. Isobaric is parallel to x-axis because pressure is constant. Along the curve, it will be isothermal because temperature is constant.

So, P→ c ⇒ Q→ a ⇒ R→ d

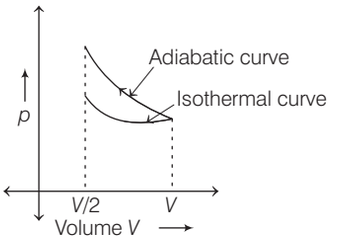
⇒ S→ b

15 A gas is compressed isothermally to half its initial volume. The same gas is compressed separately through an adiabatic process until its volume is again reduced to half. Then **[NEET 2016]**

(a) compressing the gas through adiabatic process will require more work to be done.
(b) compressing the gas isothermally or adiabatically will require the same amount of work.
(c) which of the case (whether compression through isothermal or through adiabatic process) requires more work will depend upon the atomicity of the gas.
(d) compressing the gas isothermally will require more work to be done.

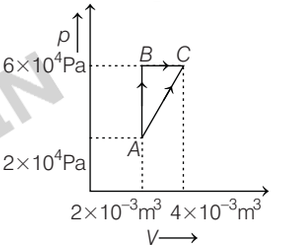
Ans. *(a)*

The solution of this question can be understood by plotting a p-V graph for the compression of a gas isothermally and adiabatically simultaneously to half of its initial volume. *i.e.*



Since, the isothermal curve is less steeper than the adiabatic curve. So, area under the p-V curve for adiabatic process has more magnitude than isothermal curve. Hence, work done in adiabatic process will be more than in isothermal process.

16 Figure below shows two paths that may be taken by a gas to go from a state A to a state C. **[CBSE AIPMT 2015]**



In process AB, 400 J of heat is added to the system and in process BC, 100 J of heat is added to the system. The heat absorbed by the system in the process AC will be

(a) 380 J (b) 500 J (c) 460 J (d) 300 J

Ans. *(c)*

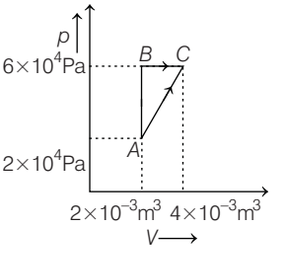
Since, initial and final points are same

So, $\Delta U_{A\to B\to C} = \Delta U_{A\to C}$ ...(i)

Also $A \to B$ is isochoric process

So $dW_{A\to B} = 0$ and $dQ = dU + dW$

So, $dQ_{A\to B} = dU_{A\to B} = 400\,J$



Next $B \to C$ is isobaric process

So, $dQ_{B\to C} = dU_{B\to C} + dW_{B\to C}$

$= dU_{B\to C} + p\Delta V_{B\to C}$

$\Rightarrow$ $100 = dU_{B\to C} + 6\times10^4(2\times10^{-3})$

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$\Rightarrow \quad dU_{B\to C} = 100 - 120 = -20$ J

From Eq. (i),

$\because \quad \Delta U_{A\to B\to C} = \Delta U_{A\to C}$

$\Rightarrow \quad \Delta U_{A\to B} + \Delta U_{B\to C} = dQ_{A\to C} - dW_{A\to C}$

$\Rightarrow 400 + (-20) = dQ_{A\to C}$

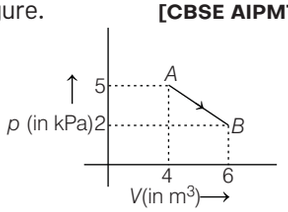
$-(p\Delta V_A + \text{Area of } \Delta ABC)$

$$\Rightarrow dQ_{A\to C} = 380 + \left(\begin{matrix}2\times10^4\times2\times10^{-3} \\ +\frac{1}{2}\times2\times10^{-3}\times4\times10^4\end{matrix}\right)$$

$= 380 + (40 + 40)$

$dQ_{A\to C} = 460$ J

17 One mole of an ideal diatomic gas undergoes a transition from A to B along a path AB as shown in the figure. **[CBSE AIPMT 2015]**

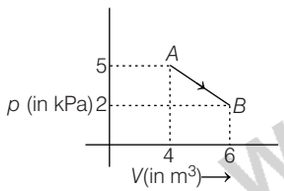


The change in internal energy of the gas during the transition is

(a) 20 kJ (b) – 20 kJ (c) 20 J (d) – 12 kJ

Ans. *(b)*

For a diatomic gas,



$C_V = \frac{5}{2}R$

The change in internal energy of gas in the transition from A to B is

$$\Delta U = nC_V dT = n\left(\frac{5R}{2}\right)(T_B - T_A)$$

$$= nR\frac{5}{2}\left(\frac{p_B V_B}{nR} - \frac{p_A V_A}{nR}\right)$$

$$= \frac{5}{2}(2\times10^3\times6 - 5\times10^3\times4)$$

$$= \frac{5}{2}\times(-8\times10^3) = -\frac{4\times10^4}{2} = -20\text{ kJ}$$

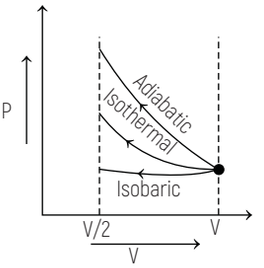
18 An ideal gas is compressed to half its initial volume by means of several process. Which of the process results in the maximum work done on the gas? **[CBSE AIPMT 2015]**

(a) Adiabatic (b) Isobaric
(c) Isochoric (d) Isothermal

Ans. *(a)*

Given, ideal gas is compressed to half its initial volume i.e.

$$V_0 = \frac{V}{2}$$



The isochoric process is one in which volume is kept constant, meaning that work done by the system will be zero. i.e.

$$W_{\text{isochoric}} = 0$$

As we know, work done on the gas = Area under curve, i.e.

$$W_{\text{adiabatic}} > W_{\text{isothermal}} > W_{\text{isobaric}}$$

19 A monoatomic gas at a pressure p, having a volume V expands isothermally to a volume 2 V and then adiabatically to a volume 16 V. The final pressure of the gas is $\left(\textbf{take } \gamma = \frac{5}{3}\right)$ **[CBSE AIPMT 2014]**

(a) 64p (b) 32p
(c) $\frac{p}{64}$ (d) 16p

Ans. *(c)*

For isothermal expansion process

$pV = p' \times 2V \qquad [\because V' = 2V]$

$p' = \frac{p}{2}$

For adiabatic expansion,

$pV^\gamma = \text{constant} \Rightarrow$

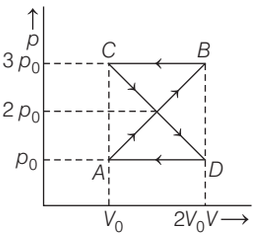
$p'V^\gamma = p''V''^\gamma$

$$\Rightarrow \quad \frac{p}{2}(2V)^{5/3} = p''(16V)^{5/3}$$

$$\Rightarrow \quad p'' = \frac{p}{2}\left[\frac{2V}{16V}\right]^{5/3} = \frac{p}{2}\left(\frac{1}{8}\right)^{5/3}$$

$$= \frac{p}{2}\left(\frac{1}{32}\right) = p/64$$

20 A thermodynamic system undergoes cyclic process $ABCDA$ as shown in figure. The work done by the system in the cycle is **[CBSE AIPMT 2014]**



(a) p_0V_0 (b) $2p_0V_0$
(c) $\frac{p_0V_0}{2}$ (d) zero

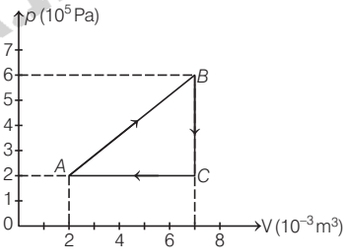
Ans. *(d)*

Work done in the cyclic process = Area bounded by the closed configuration

= Area of closed configuration

$$= \frac{1}{2}\times V_0\times p_0 - \frac{1}{2}\times V_0\times p_0 = 0\text{ (zero).}$$

21 A gas is taken through the cycle $A\to B\to C\to A$, as shown. What is the net work done by the gas? **[NEET 2013]**



(a) 2000 J (b) 1000 J
(c) Zero (d) –2000 J

Ans. *(b)*

According to question,

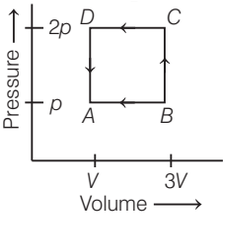
Net work done = Area enclosed in pV curve i.e. ΔABC

Area of ΔABC

$$= \frac{1}{2}\times5\times10^{-3}\times4\times10^5\text{ J}$$

$= 10^3$ J = 1000 J

22 A thermodynamic system is taken through the cycle $ABCD$ as shown in figure. Heat rejected by the gas during the cycle is **[CBSE AIPMT 2012]**



(a) 2pV (b) 4pV (c) $\frac{1}{2}pV$ (d) pV

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Ans. *(a)*

For given cyclic process,

$$\Delta U = 0 \Rightarrow Q = W$$

Also, $W = -$ area enclosed by the curve

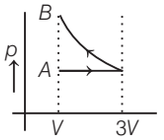
$$= -AB \times AD$$

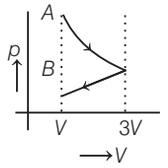
$$= -(2p - p)(3V - V)$$

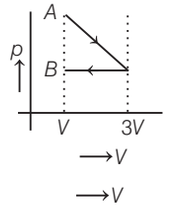
$$= -p \times 2V$$

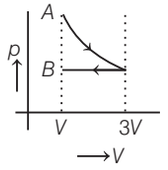
$\therefore$ Heat rejected $= 2pV$

23 One mole of an ideal gas goes from an initial state A to final state B *via* two processes. It first undergoes isothermal expansion from volume V to $3V$ and then its volume is reduced from $3V$ to V at constant pressure. The correct p-V diagram representing the two processes is **[CBSE AIPMT 2012]**

(a) 

(b) 

(c) 

(d) 

Ans. *(d)*

According to question, firstly gas expands from volume V to $3V$ and after this volume is reduced from $3V$ to V at constant pressure.

In isothermal expansion, p-V curve is rectangular hyperbola.

24 In thermodynamic processes which of the following statements is not true ? **[CBSE AIPMT 2009]**

(a) In an adiabatic process the system is insulated from the surroundings

(b) In an isochoric process pressure remains constant

(c) In an isothermal process the temperature remains constant

(d) In an adiabatic process pV^{γ} = constant

Ans. *(b)*

For an adiabatic process, there should not be any exchange of heat between the system and its surroundings. All walls of the container must be perfectly insulated. In adiabatic changes, gases obey Poisson's law, i.e., pV^{γ} = constant. In an isochoric process, volume remains constant and for isobaric process, pressure remains constant.

25 Which of the following processes is reversible? **[CBSE AIPMT 2005]**

(a) Transfer of heat by radiation

(b) Electrical heating of a nichrome wire

(c) Transfer of heat by conduction

(d) Isothermal compression

Ans. *(d)*

(a) It is the process by which heat is transmitted from one place to another without heating the intervening medium. Hence, it is not a reversible process.

(b) Nichrome wire is made of alloy and has high resistance. When current is passed through it, heat is produced. So, here electrical energy is converted into heat energy. Hence, it is not a reversible process.

(c) It is the process by which heat is transmitted from one point to another through a substance in the direction of fall of temperature without the actual movement of the particles of the substances themselves. Hence, it cannot be reversible.

(d) Isothermal compression is reversible, for example-Carnot cycle, Heat engine.

Thus, choice (d) is correct.

26 One mole of an ideal gas at an initial temperature of T K does $6R$ joules of work adiabatically. If the ratio of specific heats of this gas at constant pressure and at constant volume is 5/3, the final temperature of gas will be **[CBSE AIPMT 2004]**

(a) $(T + 2.4)$ K

(b) $(T - 2.4)$ K

(c) $(T + 4)$ K

(d) $(T - 4)$ K

Ans. *(d)*

In an adiabatic process,

$Q = 0$

So, from Ist law of thermodynamics,

$\Delta Q = \Delta U + \Delta W$

As $\Delta Q = 0$

so, $W = -\Delta U = -nC_v \Delta T$

$$= -n\left(\frac{R}{\gamma - 1}\right)(T_f - T_i)$$

$$= \frac{nR}{\gamma - 1}(T_i - T_f) \quad \ldots(i)$$

Given, work done, $W = 6R$ J, $n = 1$ mol,

$$R = 8.31 \text{ J/mol-K}, \gamma = \frac{5}{3}, T_i = T \text{ K}$$

Substituting given values in Eq. (i), we get

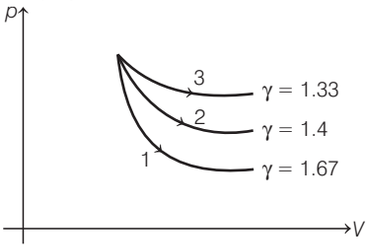
$$\therefore \quad 6R = \frac{R}{(5/3 - 1)}(T - T_f)$$

$$\Rightarrow \quad 6R = \frac{3R}{2}(T - T_f) \Rightarrow T - T_f = 4$$

$$\therefore \quad T_f = (T - 4) \text{ K}$$

Adiabatic expansions of mono, dia and polyatomic gases are shown below.

1 → monoatomic 2 → diatomic 3 → polyatomic



27 If the ratio of specific heat of a gas at constant pressure to that at constant volume is γ, the change in internal energy of a mass of gas when the volume changes from V to $2V$ at constant pressure p is **[CBSE AIPMT 1998]**

(a) $\frac{R}{(\gamma - 1)}$ (b) pV (c) $\frac{pV}{(\gamma - 1)}$ (d) $\frac{\gamma pV}{(\gamma - 1)}$

Ans. *(c)*

Change in internal energy of a gas having atomicity γ is given by

$$\Delta U = \frac{1}{(\gamma - 1)}(p_2V_2 - p_1V_1)$$

Given, $V_1 = V, V_2 = 2V$

So, $$\Delta U = \frac{1}{\gamma - 1}[p \times 2V - p \times V]$$

$$= \frac{1}{\gamma - 1} \times pV = \frac{pV}{\gamma - 1}$$

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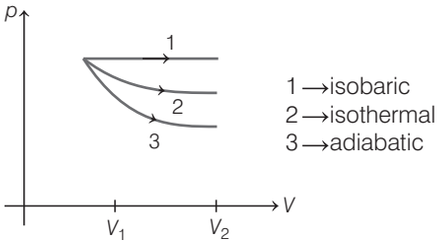
28 A sample of gas expands from volume V_1 to V_2. The amount of work done by the gas is greatest when the expansion is

[CBSE AIPMT 1997]

(a) adiabatic
(b) isobaric
(c) isothermal
(d) Equal in all above cases

Ans. ***(b)***

The *p-V* diagram for isobaric, isothermal and adiabatic processes of an ideal gas is shown in graph below



In thermodynamics, for some change in volume, the work done is maximum for the curve having maximum area enclosed with the volume axis.

Area enclosed by the curve

$\propto$ (Slope of curve)

Note

$(\text{slope})_{\text{isobaric}} < (\text{slope})_{\text{isothermal}} < (\text{slope})_{\text{adiabatic}}$

$\Rightarrow (\text{Area})_{\text{isobaric}} > (\text{Area})_{\text{isothermal}} > (\text{Area})_{\text{adiabatic}}$

Hence, work done is maximum in isobaric process.

$$(\text{Slope})_{\text{adiabatic}} = -\gamma\left(\frac{p}{V}\right)$$

and $(\text{Slope})_{\text{isothermal}} = -\frac{p}{V}$

$\therefore \quad (\text{Slope})_{\text{adiabatic}} = \gamma \times (\text{slope})_{\text{isothermal}}$

Slope of adiabatic curve is always steeper than that of isothermal curve.

29 An ideal gas undergoing adiabatic change has the following pressure-temperature relationship

[CBSE AIPMT 1996]

(a) $p^{\gamma-1}T^{\gamma}$ = constant
(b) $p^{\gamma}T^{\gamma-1}$ = constant
(c) $p^{\gamma}T^{1-\gamma}$ = constant
(d) $p^{1-\gamma}T^{\gamma}$ = constant

Ans. ***(d)***

The adiabatic relation between *p* and *V* for a perfect gas is

$$pV^{\gamma} = k \qquad \ldots(i)$$

From standard gas equation

$$pV = RT \quad \text{or} \quad V = \frac{RT}{p}$$

Putting value of *V* in Eq. (i)

$$p\left(\frac{RT}{p}\right)^{\gamma} = k$$

or $\quad p^{1-\gamma}T^{\gamma} = \frac{k}{R^{\gamma}} = \text{another constant}$

i.e., $\quad p^{1-\gamma}T^{\gamma} = \text{constant}$

30 An ideal gas *A* and a real gas *B* have their volumes increased from *V* to 2*V* under isothermal conditions. The increase in internal energy

[CBSE AIPMT 1993]

(a) will be same in both *A* and *B*
(b) will be zero in both the gases
(c) of *B* will be more than that of *A*
(d) of *A* will be more than that of *B*

Ans. ***(b)***

A change in pressure and volume of a gas without any change in its temperature is called an isothermal change. In such a change, there is a free exchange of heat between the gas and its surroundings.

$\therefore \quad T = \text{constant}, \quad \Delta T = 0$

So, internal energy (*U*) remains constant 0.

31 Which of the following is not thermodynamical function ?

[CBSE AIPMT 1993]

(a) Enthalpy (b) Work done
(c) Gibb's energy (d) Internal energy

Ans. ***(b)***

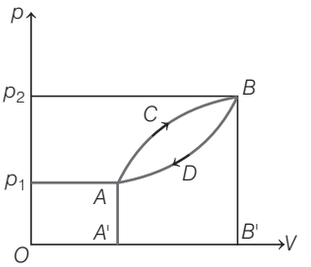
The thermodynamic state of a homogeneous system may be represented by certain specific thermodynamic variables such as pressure *p*, volume *V*, temperature *T* and entropy *S*. Out of these four variables, any two are independent and when they are known the others may be determined. Thus, there are only two independent variables and the others may be considered their functions. For complete knowledge of the system certain relations are required and for this purpose we introduce some functions of variables *p*, *V*, *T* and *S* known as thermodynamic functions. There are four principal thermodynamic functions

(i) Internal energy (*U*)
(ii) Helmholtz function (*F*)
(iii) Enthalpy (*H*)
(iv) Gibb's energy (*G*)

Hence, work done is not thermodynamic function.

32 A thermodynamic system is taken from state *A* to *B* along *ACB* and is brought back to *A* along *BDA* as shown in the *p-V* diagram. The net work done during the complete cycle is given by the area

[CBSE AIPMT 1992]



(a) $p_1 A C B p_2 p_1$ (b) $A C B B' A' A$
(c) $A C B D A$ (d) $A D B B' A' A$

Ans. ***(c)***

Work done during path *ACB*

= area $ACBB'A'A$

Work done during path *BDA*

= area $BDAA'B'B$

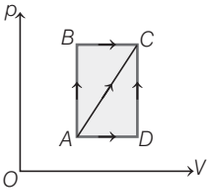
$\therefore$ Work done during going from *ACB* and then to *BDA* path is

= area $ACB B'A'A$ – area $BDAA'B'B$

= area $ACBDA$

Net work done in cyclic process is given by area under the cycle.

33 A thermodynamic process is shown in the figure. The pressure and volumes corresponding to some points in the figure are



$p_A = 3\times10^4$ pa,, $V_A = 2\times10^{-3}$ m³
$p_B = 8\times10^4$ pa, $V_B = 5\times10^{-3}$ m³

In process *AB*, 600 J of heat is added to the system and in process *BC*, 200 J of heat is added to the system. The change in internal energy of the system in process *AC* would be

[CBSE AIPMT 1991]

(a) 560 J (b) 800 J
(c) 600 J (d) 640 J

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Ans. *(a)*

For path AB, applying first law of thermodynamics

$$dQ = dU + dW \text{ or } dQ = U_B - U_A + dW$$

or $600 = U_B - U_A + 0$

(for isochoric process $dV = 0$ so, $dW = 0$)

$$U_B - U_A = 600 \quad ...(i)$$

For path BC,

$$dQ = dU + dW$$

$$\therefore \quad 200 = U_C - U_B + p_B (V_C - V_B)$$

(as BC is isobaric process)

$$\therefore \quad 200 = U_C - U_B + 8 \times 10^4 (5 \times 10^{-3} - 2 \times 10^{-3})$$

or $200 = U_C - U_B + 240$

$$\therefore \quad U_C - U_B = -40 \text{ J} \quad ...(ii)$$

For AC, change in internal energy can be calculated by adding Eqs. (i) and (ii),

$$= U_C - U_A$$
$$= U_C - U_B + U_B - U_A$$
$$= -40 + 600 = 560 \text{ J}$$

TOPIC 3

Heat Engine, Second Law of Thermodynamics and Carnot Engine

33 The efficiency of a Carnot engine depends upon **[NEET (Oct.) 2020]**

(a) the temperature of the sink only
(b) the temperatures of the source and sink
(c) the volume of the cylinder of the engine
(d) the temperature of the source only

Ans. *(b)*

Efficiency of Carnot engine is given as

$$\eta = 1 - \frac{T_2}{T_1}$$

where, T_2 = temperature of sink

and T_1 = temperature of source.

Hence, η depends upon the temperature of source and sink both.

34 The efficiency of an ideal heat engine working between the freezing point and boiling point of water, is **[NEET 2018]**

(a) 6.25% (b) 20% (c) 26.8% (d) 12.5%

Ans. *(c)*

Efficiency of an ideal heat engine is given as

$$\eta = 1 - \frac{T_2}{T_1}$$

where, T_1 is the temperature of the source and T_2 is the temperature of the sink.

Here, $T_1 = 100 + 273 = 373 \text{ K}$

$T_2 = 0 + 273 = 273 \text{ K}$

$$\Rightarrow \quad \eta = 1 - \frac{273}{373}$$

$$= \frac{373 - 273}{373} = \frac{100}{373} = 0.268$$

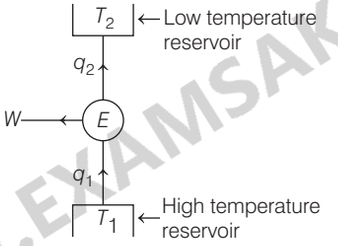
$$\therefore \quad \eta \% = 0.268 \times 100 = 26.8 \%$$

35 A Carnot engine having an efficiency of $\frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[NEET 2017]**

(a) 1 J (b) 90 J (c) 99 J (d) 100 J

Ans. *(b)*

Consider schematic diagram for a Carnot engine as shown below.



In case of engine,

$$\text{engine efficiency} = \frac{\text{work}}{\text{heat absorbed}} = \frac{W}{q_1}$$

$$\therefore \quad \frac{W}{q_1} = \frac{1}{10}$$

$$\Rightarrow \quad \frac{10 \text{ J}}{q_1} = \frac{1}{10} \text{ or } q_1 = 100 \text{ J}$$

When this engine is reversed, it takes in work W and heat q_2 from cold reservoir and ejects 100 J of heat to hot reservoir.

$$\therefore \quad W + q_2 = q_1$$

$$\Rightarrow \quad 10 + q_2 = 100 \text{ or } q_2 = 90 \text{ J}$$

36 A refrigerator works between 4°C and 30°C. It is required to remove 600 calories of heat every second in order to keep the temperature of the refrigerated space constant. The power required is

(Take, 1 cal = 4.2 Joules) **[NEET 2016]**

(a) 23.65 W (b) 236.5 W
(c) 2365 W (d) 2.365 W

Ans. *(b)*

Given, temperature of source,

$$T = 30°\text{C} = 30 + 273 \Rightarrow T_1 = 303 \text{ K}$$

Temperature of sink, $T_2 = 4°\text{C} = 4 + 273$

$$T_2 = 277 \text{ K}$$

As, we know that

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \Rightarrow \frac{Q_2 + W}{Q_2} = \frac{T_1}{T_2}$$

$\{\because W = Q_1 - Q_2\}$

where Q_2 is the amount of heat drawn from the sink (at T_2), W is workdone on working substance, Q_1 is amount of heat rejected to source (at room temperature T_1).

$$\Rightarrow \quad WT_2 + T_2 Q_2 = T_1 Q_2$$

$$\Rightarrow \quad WT_2 = T_1 Q_2 - T_2 Q_2$$

$$\Rightarrow \quad WT_2 = Q_2 (T_1 - T_2)$$

$$\Rightarrow \quad W = Q_2 \left(\frac{T_1}{T_2} - 1 \right)$$

$$\Rightarrow \quad W = 600 \times 4.2 \times \left(\frac{303}{277} - 1 \right)$$

$$W = 600 \times 4.2 \times \left(\frac{26}{277} \right)$$

$$W = 236.5 \text{ Joules}$$

$$\text{Power} = \frac{\text{Work done}}{\text{Time}} = \frac{W}{t} = \frac{236.5}{1}$$

$$= 236.5 \text{ W}$$

37 The temperature inside a refrigerator is t_2 °C and the room temperature is t_1 °C. The amount of heat delivered to the room for each joule of electrical energy consumed ideally will be **[NEET 2016]**

(a) $\frac{t_1}{t_1 - t_2}$ (b) $\frac{t_1 + 273}{t_1 - t_2}$
(c) $\frac{t_2 + 273}{t_1 - t_2}$ (d) $\frac{t_1 + t_2}{t_1 + 273}$

Ans. *(b)*

For a refrigerator, we know that

$$\frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

where,

Q_1 = amount of heat delivered to the room

W = electrical energy consumed

T_1 = room temperature = $t_1 + 273$

T_2 = temperature of sink = $t_2 + 273$

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$$\therefore \quad \frac{Q_1}{1} = \frac{t_1 + 273}{t_1 + 273 - (t_2 + 273)}$$

$$\Rightarrow \quad Q_1 = \frac{t_1 + 273}{t_1 - t_2}$$

38 A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is **[CBSE AIPMT 2015]**

(a) 100 J (b) 99 J
(c) 90 J (d) 1 J

Ans. *(c)*

As, $Q_1 + W = Q_2$

Given, $\eta = \frac{1}{10}$

Now, using $\eta = 1 - \frac{T_1}{T_2}$

So, $\frac{1}{10} = 1 - \frac{T_1}{T_2} \Rightarrow \frac{T_1}{T_2} = \frac{9}{10}$

Now $\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \Rightarrow \frac{Q_1}{Q_1 + W} = \frac{9}{10}$

$\Rightarrow \quad 10Q_1 = 9Q_1 + 9W$

$\Rightarrow \quad Q_1 = 9W = 9 \times 10 = 90\ \text{J}$

39 The coefficient of performance of a refrigerator is 5. If the temperature inside freezer is $-20°C$, the temperature of the surroundings to which it rejects heat is **[CBSE AIPMT 2015]**

(a) 31°C (b) 41°C
(c) 11°C (d) 21°C

Ans. *(a)*

Key Concept Coefficient of performance (β) of a refrigerator is defined as the ratio of quantity of heat removed per cycle (Q_2) to the work done on the working substance per cycle to remove this heat.

Given, coefficient of performance of a refrigerator, $\beta = 5$

Temperature of surface, i.e. inside freezer,

$$T_2 = -20°C = -20 + 273 = 253\ \text{K}$$

Temperature of surrounding, i.e. heat rejected outside $T_1 = ?$

So, $\beta = \frac{T_2}{T_1 - T_2} \Rightarrow 5 = \frac{253}{T_1 - 253}$

$\Rightarrow \quad 5T_1 - 1265 = 253$

$\Rightarrow \quad 5T_1 = 1518$

$$T_1 = \frac{1518}{5} = 303.6\ \text{K}$$

$$T_1 = 303.6 - 273 = 31°C$$

40 An engine has an efficiency of $\frac{1}{6}$. When the temperature of sink is reduced by 62°C, its efficiency is doubled. Temperature of the source is **[CBSE AIPMT 2007]**

(a) 124°C (b) 37°C (c) 62°C (d) 99°C

Ans. *(d)*

Efficiency of engine is given by

$$\eta = 1 - \frac{T_2}{T_1}$$

T_2 = temperature of sink

T_1 = temperature of source

$$\therefore \quad \frac{T_2}{T_1} = 1 - \eta = 1 - \frac{1}{6} = \frac{5}{6} \qquad \ldots(i)$$

In other case,

$$\frac{T_2 - 62}{T_1} = 1 - \eta = 1 - \frac{2}{6} = \frac{2}{3} \qquad \ldots(ii)$$

or $T_2 - 62 = \frac{2}{3}T_1 = \frac{2}{3} \times \frac{6}{5}T_2$ [Using Eq. (i)]

or $\frac{1}{5}T_2 = 62$

$\therefore \quad T_2 = 310\ \text{K}$

$= 310 - 273°C = 37°C$

Here, $T_1 = \frac{6}{5}T_2 = \frac{6}{5} \times 310$

$= 372\ \text{K} = 372 - 273$

$= 99°C$

41 A Carnot engine whose sink is at 300 K has an efficiency of 40%. By how much should the temperature of source be increased so as to increase its efficiency by 50% of original efficiency ? **[CBSE AIPMT 2006]**

(a) 275 K (b) 325 K (c) 250 K (d) 380 K

Ans. *(c)*

The efficiency of Carnot engine is defined as the ratio of work done to the heat supplied i.e.

$$\eta = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$= 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Here, T_1 is the temperature of source, T_2 is the temperature of sink, Q_1 is heat absorbed and Q_2 heat rejected

As given, $\eta = 40\% = \frac{40}{100} = 0.4$ and $T_2 = 300\ \text{K}$

So $0.4 = 1 - \frac{300}{T_1}$

$\Rightarrow \quad T_1 = \frac{300}{1 - 0.4} = \frac{300}{0.6}$

$= 500\ \text{K}$

Let temperature of the source be increased by x K, then efficiency becomes

$\eta' = 40\% + 50\%$ of η

$= \frac{40}{100} + \frac{50}{100} \times 0.4$

$= 0.4 + 0.5 \times 0.4 = 0.6$

Hence, $0.6 = 1 - \frac{300}{500 + x}$

$\Rightarrow \quad \frac{300}{500 + x} = 0.4$

$\Rightarrow \quad 500 + x = \frac{300}{0.4} = 750$

$\therefore \quad x = 750 - 500 = 250\ \text{K}$

All reversible heat engines working between same temperatures are equally efficient and no heat engine can be more efficient than Carnot engine (as it is ideal).

42 An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat at higher temperature. Amount of heat converted to work is **[CBSE AIPMT 2005]**

(a) 2.4×10^4 cal (b) 6×10^4 cal
(c) 1.2×10^4 cal (d) 4.8×10^4 cal

Ans. *(c)*

According to the Carnot cycle in heat engine

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$$

Given, heat absorbed, $Q_1 = 6 \times 10^4$ cal,

Temperature of source,

$T_1 = 227 + 273 = 500\ \text{K}$

Temperature of sink,

$T_2 = 127 + 273 = 400\ \text{K}$

$\therefore \quad \frac{Q_2}{6 \times 10^4} = \frac{400}{500}$

$\Rightarrow$ Heat rejected, $Q_2 = \frac{4}{5} \times 6 \times 10^4$

$= 4.8 \times 10^4$ cal

Now, heat converted to work

$W = Q_1 - Q_2 = 6.0 \times 10^4 - 4.8 \times 10^4$

$= 1.2 \times 10^4$ cal

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43 An ideal gas heat engine operates in a Carnot cycle between 227°C and 127°C. It absorbs 6 kcal at the higher temperature. The amount of heat (in kcal) converted into work is equal to **[CBSE AIPMT 2003]**

(a) 1.6 (b) 1.2 (c) 4.8 (d) 3.5

Ans. *(b)*

The efficiency of heat engine is $\eta = 1 - \frac{T_2}{T_1}$

or $\frac{W}{Q_1} = 1 - \frac{T_2}{T_1}$

T_2 = Temperature of sink

T_1 = Temperature of source

W = Work done

Given, Q_1 = heat absorbed from the source

$= 6$ kcal

$T_1 = 227 + 273 = 500$ K

and $T_2 = 127 + 273 = 400$ K

Hence, $\frac{W}{6} = 1 - \frac{400}{500}$

or $\frac{W}{6} = \frac{100}{500}$

or $W = 1.2$ kcal

Thus, amount of heat converted into work is 1.2 kcal.

44 The efficiency of Carnot engine is 50% and temperature of sink is 500 K. If the temperature of source is kept constant and its efficiency is to be raised to 60%, then the required temperature of the sink will be **[CBSE AIPMT 2002]**

(a) 600 K (b) 500 K (c) 400 K (d) 100 K

Ans. *(c)*

Efficiency of the Carnot engine is given by

$$\eta = 1 - \frac{T_2}{T_1} \quad ...(i)$$

where, T_1 = temperature of source

T_2 = temperature of sink

Given, $\eta = 50\% = 0.5$, $T_2 = 500$ K

Substituting in Eq. (i), we have

$0.5 = 1 - \frac{500}{T_1}$ or $\frac{500}{T_1} = 0.5$

$\therefore \quad T_1 = \frac{500}{0.5} = 1000$ K

Now, the temperature of sink is changed to T_2' and the efficiency becomes 60% i.e., 0.6.

Using Eq. (i), we get

$0.6 = 1 - \frac{T_2'}{1000}$

or $\frac{T_2'}{1000} = 1 - 0.6 = 0.4$ or

$T_2' = 0.4 \times 100 = 400$ K

Carnot engine is not a practical engine because many ideal situations have been assumed while designing this engine which cannot be obtained practically.

45 The temperatures of source and sink of a heat engine are 127°C and 27°C respectively. An inventor claims its efficiency to be 26%, then, **[CBSE AIPMT 2001]**

(a) it is impossible

(b) it is possible with high probability

(c) it is possible with low probability

(d) Data is insufficient

Ans. *(a)*

Efficiency of heat engine is,

$\eta = 1 - \frac{T_2}{T_1}$ or $\eta = \frac{T_1 - T_2}{T_1}$

T_2 = temperature of sink

T_1 = temperature of source

Given, $T_1 = 273 + 127 = 400$ K

$T_2 = 273 + 27 = 300$ K

$\therefore \quad \eta = \frac{400 - 300}{400} = \frac{100}{400} = 0.25 = 25\%$

Hence, 26% efficiency is impossible for a given heat engine.

46 An engine takes heat from a reservoir and converts its 1/6 part into work. By decreasing temperature of sink by 62°C, its efficiency becomes double. The temperatures of source and sink must be **[CBSE AIPMT 2000]**

(a) 90°C, 37°C (b) 99°C, 37°C

(c) 372°C, 37°C (d) 206°C, 37°C

Ans. *(b)*

If T_1 is temperature of source and T_2 the temperature of sink, the efficiency of engine

$\eta = \frac{\text{Work done}\,(W)}{\text{Heat taken}\,(Q_1)} = 1 - \frac{T_2}{T_1}$

$\therefore \quad 1 - \frac{T_2}{T_1} = \frac{1}{6} \quad ...(i)$

When temperature of sink is reduced by 62°C, then temperature of sink

$T_2' = T_2 - 62$

$\therefore \quad \eta' = 1 - \frac{T_2'}{T_1}$

As according to question efficiency becomes double

So, $\eta' = 2\eta = \frac{2}{6} = \frac{1}{3}$

$\therefore \quad \frac{1}{3} = 1 - \frac{T_2 - 62}{T_1} \quad ...(ii)$

From Eq. (i) $\frac{T_2}{T_1} = \frac{5}{6} \quad ...(iii)$

From Eq. (ii) $\frac{T_2 - 62}{T_1} = \frac{2}{3} \quad ...(iv)$

Dividing Eq. (iii) by Eq. (iv)

$\frac{T_2}{T_2 - 62} = \frac{5}{4}$

$\Rightarrow \quad 4T_2 = 5T_2 - 310$

$\Rightarrow \quad T_2 = 310$ K

and from Eq. (iii), we have

$\frac{310}{T_1} = \frac{5}{6} \Rightarrow T_1 = 372$ K

Hence, $T_1 = 372$ K $= 372 - 273 = 99$°C

and $T_2 = 310$ K $= 310 - 273 = 37$°C

As kinetic energy of a gas depends on its atomicity.

47 The efficiency of a Carnot engine operating between temperatures of 100°C and −23°C will be **[CBSE AIPMT 1997]**

(a) $\frac{100 - 23}{273}$ (b) $\frac{100 + 23}{373}$

(c) $\frac{100 + 23}{100}$ (d) $\frac{100 - 23}{100}$

Ans. *(b)*

Efficiency of Carnot engine is given by

$$\eta = 1 - \frac{T_2}{T_1} = \frac{T_1 - T_2}{T_1} \quad ...(i)$$

Given, T_1 = temperature of reservoir

$= 100 + 273 = 373$ K

T_2 = temperature of sink

$= -23 + 273 = 250$ K

Substituting in Eq. (i), we get

$\therefore \quad \eta = \frac{373 - 250}{373} = \frac{123}{373}$

$= \frac{100 + 23}{373}$

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12

Kinetic Theory

TOPIC 1
Kinetic Theory of Gases and Gas Laws

01 The mean free path l for a gas molecule depends upon diameter, d of the molecule as **[NEET (Oct.) 2020]**

(a) $l \propto \frac{1}{d^2}$ (b) $l \propto d$ (c) $l \propto d^2$ (d) $l \propto \frac{1}{d}$

Ans. *(a)*

The mean free path l for a gas molecule is given as

$$l = \frac{1}{\sqrt{2}\pi n d^2} \Rightarrow l \propto \frac{1}{d^2}$$

where, d = diameter of molecule of gas.

02 An ideal gas equation can be written as $p = \frac{\rho RT}{M_0}$

where, ρ and M_0 are respectively, **[NEET (Oct.) 2020]**

(a) mass density, mass of the gas
(b) number density, molar mass
(c) mass density, molar mass
(d) number density, mass of the gas

Ans. *(a)*

Ideal gas equation is given as

$$p = \frac{\rho RT}{M_0} \Rightarrow p \cdot \frac{M_0}{\rho} = RT$$

$$\Rightarrow \quad pV = RT$$

where, $V = \frac{M_0}{\rho}$

Hence, ρ and M_0 are mass density and mass of gas, respectively.

03 The mean free path λ for a gas, with molecular diameter d and number density n can be expressed as **[NEET (Sep.) 2020]**

(a) $\frac{1}{\sqrt{2}\, n\pi d^2}$ (b) $\frac{1}{\sqrt{2}\, n^2\pi d^2}$
(c) $\frac{1}{\sqrt{2}\, n^2\pi^2 d^2}$ (d) $\frac{1}{\sqrt{2}\, n\pi d}$

Ans. *(a)*

The mean free path λ for a gas, with molecular diameter d and number density n is given by the relation

$$\lambda = \frac{1}{\sqrt{2}\, n\pi d^2}$$

Hence, correct option is (a).

04 A cylinder contains hydrogen gas at pressure of 249 kPa and temperature 27°C. Its density is ($R = 8.3$ J mol^{-1} K^{-1}) **[NEET (Sep.) 2020]**

(a) 0.2 kg/m^3 (b) 0.1 kg/m^3
(c) 0.02 kg/m^3 (d) 0.5 kg/m^3

Ans. *(a)*

Given,

pressure $p = 249\,\text{kPa} = 249 \times 10^3$ Pa

Temperature, $T = 27°\text{C}$

$= 273 + 27\,\text{K} = 300\,\text{K}$

Density, $\rho = ?$

As, from ideal gas equation,

$$pV = nRT$$

$$\Rightarrow \quad pV = \frac{m}{M}RT \qquad \left[\text{as } n = \frac{m}{M}\right]$$

$$\Rightarrow \quad pVM = mRT$$

$$\Rightarrow \quad pM = \frac{m}{V}RT = \rho RT \qquad \left[\text{as } \frac{m}{V} = \rho\right]$$

$$\Rightarrow \quad \rho = \frac{pM}{RT}$$

$$= \frac{249 \times 10^3 \times 2 \times 10^{-3}}{8.3 \times 300}$$

[$\because$ for hydrogen gas, $M = 2\,\text{g} = 2 \times 10^{-3}$ kg]

$$\Rightarrow \quad \rho = 0.2\,\text{kg/m}^3$$

Hence, correct option is (a).

05 Increase in temperature of a gas filled in a container would lead to **[NEET (National) 2019]**

(a) increase in its kinetic energy
(b) decrease in its pressure
(c) decrease in intermolecular distance
(d) increase in its mass

Ans. *(a)*

As the temperature of gas in the container is increased, the kinetic energy also increases. This is because the average kinetic energy of a gas is given by

$$\text{KE} = \frac{f}{2}nRT \qquad \ldots(\text{i})$$

where, f = degree of freedom,

n = number of moles of gas molecules,

R = universal gas constant, and

T = absolute temperature of the gas.

From Eq. (i),

$$\text{KE} \propto T$$

option (b) is incorrect as increase in temperature will lead to increase in pressure as $p \propto T$. Other options (c) and (d) are also incorrect as molecular distance increases while mass remains the same for increase in the temperature.

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06 At what temperature will the rms speed of oxygen molecules become just sufficient for escaping from the Earth's atmosphere?
(Given: mass of oxygen molecule, $m = 2.76 \times 10^{-26}$ kg, Boltzmann's constant $k_B = 1.38 \times 10^{-23}$ J K^{-1}) **[NEET 2018]**
(a) 5.016×10^4 K
(b) 8.326×10^4 K
(c) 2.508×10^4 K
(d) 1.254×10^4 K

Ans. *(b)*

Key Concept The minimum velocity with which the body must be projected vertically upwards, so that it could escape from the Earth's atmosphere, is its *escape velocity* (v_e).

As, $v_e = \sqrt{2gR}$

Substituting the value of g (9.8 ms^{-2}) and radius of Earth ($R = 6.4 \times 10^6$ m), we get

$$v_e = \sqrt{2 \times 9.8 \times 6.4 \times 10^6}$$
$$\cong 11.2 \text{ km s}^{-1} = 11200 \text{ m s}^{-1}$$

Let the temperature of molecule be T when it attains v_e.

According to the question,

$$v_{rms} = v_e$$

where, v_{rms} is the rms speed of the oxygen molecule.

$$\Rightarrow \quad \sqrt{\frac{3k_BT}{m_{O_2}}} = 11.2 \times 10^3$$

or $$T = \frac{(11.2 \times 10^3)^2 \, (m_{O_2})}{(3k_B)}$$

Substituting the given values, i.e.,

$R_B = 1.38 \times 10^{-23}$ JK^{-1} and

$m_{O_2} = m = 2.76 \times 10^{-26}$ kg

We get,

$$T = \frac{(11.2 \times 10^3)^2 \, (2.76 \times 10^{-26})}{(3 \times 1.38 \times 10^{-23})}$$
$$= 8.3626 \times 10^4 \text{ K}$$

07 The molecules of a given mass of a gas have r.m.s. velocity of 200 ms^{-1} at 27°C and 1.0×10^5 Nm^{-2} pressure. When the temperature and pressure of the gas are respectively, 127°C and 0.05×10^5 Nm^{-2}, the rms velocity of its molecules in ms^{-1} is **[NEET 2016]**
(a) $\frac{400}{\sqrt{3}}$ (b) $\frac{100\sqrt{2}}{3}$ (c) $\frac{100}{3}$ (d) $100\sqrt{2}$

Ans. *(a)*

It is given that

$v_{rms} = 200 \text{ ms}^{-1}, T_1 = 300 \text{ K}, P_1 = 10^5 \text{ N/m}^2$

$T_2 = 400 \text{ K}, P_2 = 0.05 \times 10^5 \text{ N/m}^2$

As, rms velocity of gas molecules,

$$\because \quad v_{rms} \propto \sqrt{T} \qquad \left(\because v_{rms} = \sqrt{\frac{3RT}{m}}\right)$$

For two different cases

$$\Rightarrow \quad \frac{(v_{rms})_1}{(v_{rms})_2} = \sqrt{\frac{T_1}{T_2}}$$

$$\Rightarrow \quad \frac{200}{(v_{rms})_2} = \sqrt{\frac{300}{400}} = \sqrt{\frac{3}{4}}$$

$$\Rightarrow \quad (v_{rms})_2 = \frac{2}{\sqrt{3}} \times 200 = \frac{400}{\sqrt{3}} \text{ ms}^{-1}$$

08 A given sample of an ideal gas occupies a volume V at a pressure p and absolute temperature T. The mass of each molecule of the gas is m. Which of the following gives the density of the gas? **[NEET 2016]**
(a) $p/(kT)$ (b) $pm/(kT)$
(c) $p/(kTV)$ (d) mkT

Ans. *(b)*

As we know that

Pressure, $p = \frac{1}{3} \cdot \frac{nm}{V} v_{rms}^2$

$\because nm$ = mass of the gas, V = volume of the gas

$\therefore \frac{mn}{V}$ = density of the gas. Thus,

$$p = \frac{1}{2} p v_{rms}^2 = \frac{1}{3} \rho \frac{3RT}{M_0} = \frac{\rho RT}{M_0} \qquad \left(\because v_{rms} = \sqrt{\frac{3RT}{M_0}}\right)$$

$$\rho = \frac{pM_0}{RT} = \frac{pmN_A}{kN_AT} \qquad [\because R = N_Ak \text{ and } M_0 = mN_A]$$

$$\rho = \frac{pm}{kT}$$

09 4.0 g of a gas occupies 22.4 L at NTP. The specific heat capacity of the gas at constant volume is 5.0 JK^{-1} mol^{-1}. If the speed of sound in this gas at NTP is 952 ms^{-1}, then the heat capacity at constant pressure is (Take gas constant $R = 8.3$ JK^{-1} mol^{-1}) **[CBSE AIPMT 2015]**
(a) 8.0 JK^{-1} mol^{-1} (b) 7.5 JK^{-1} mol^{-1}
(c) 7.0 JK^{-1} mol^{-1} (d) 8.5 JK^{-1} mol^{-1}

Ans. *(a)*

Given, $M = 4$ gm, $V = 22.4$ L,
$C_V = 5$ JK^{-1}mol^{-1}
$v_{sound} = 952$ m/s, $C_p = ?$

As, velocity of sound, $v_{sound} = \sqrt{\frac{\gamma pV}{M}}$

$$\Rightarrow \quad \gamma = \frac{M}{pV} V_{sound}^2 = \frac{C_p}{C_V}$$

So, heat capacity at constant pressure,

$$C_p = C_V \left[\frac{M}{pV}\right] v_{sound}^2$$
$$= 5\left[\frac{4 \times 10^{-3}}{10^5 \times 22.4 \times 10^{-3}}\right](952)^2$$
$$= \frac{20}{22.4} \times (952)^2 \times 10^{-5}$$
$$= 809.200 \times 10^{-5}$$
$$= 8.09 \text{ J/mol K}$$

10 Two vessels separately contain two ideal gases A and B at the same temperature, the pressure of A being twice that of B. Under such conditions, the density of A is found to be 1.5 times the density of B. The ratio of molecular weight of A and B is **[CBSE AIPMT 2015]**
(a) $\frac{2}{3}$ (b) $\frac{3}{4}$
(c) 2 (d) $\frac{1}{2}$

Ans. *(b)*

Vessel-I	Vessel-II
Ideal Gas A	Ideal Gas B
T	T
$\rho_A = 1.5\rho_B$	ρ_B
$\rho_A = 2\rho_B$	p_B

According to ideal gas equation, we have

Pressure, $p = \frac{\rho RT}{M}$, where M is molecular weight of ideal gas.

Such that, $\frac{p}{\rho} = \frac{RT}{M}$

$$\Rightarrow \quad M = \frac{\rho RT}{P}$$

where, R and T are constants.

So, $M \propto \frac{\rho}{p}$

$$\Rightarrow \quad \frac{M_A}{M_B} = \frac{\rho_A}{\rho_B} \times \frac{p_B}{p_A}$$
$$= 1.5 \times \frac{1}{2} = 0.75 = \frac{3}{4}$$

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11 The mean free path of molecules of a gas, (radius r) is inversely proportional to **[CBSE AIPMT 2014]**

(a) r^3 (b) r^2 (c) r (d) $\sqrt{r}$

Ans. *(d)*

Mean free path (l) is given by

$$l = \frac{1}{\sqrt{2}n\pi d^2} \Rightarrow l \propto \frac{1}{d^2}$$

So, $l \propto \frac{1}{r^2}$

$\left[r = \text{radius of the molecules of gas}\right]$

12 The molar specific heats of an ideal gas at constant pressure and volume are denoted by C_p and C_V respectively. If $\gamma = \frac{C_p}{C_V}$ and R is the universal gas constant, then C_V is equal to **[NEET 2013]**

(a) $\frac{1+\gamma}{1-\gamma}$ (b) $\frac{R}{(\gamma-1)}$ (c) $\frac{(\gamma-1)}{R}$ (d) γR

Ans. *(b)*

As we know that

$$C_p - C_V = R$$

$$C_p = R + C_V$$

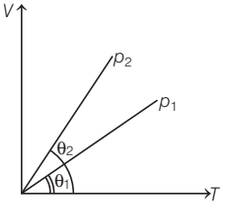
and $\frac{C_p}{C_V} = \gamma$ (given)

So, $\frac{R + C_V}{C_V} = \gamma \Rightarrow \gamma C_V = R + C_V$

$\Rightarrow \gamma C_V - C_V = R$

$\Rightarrow C_V = \frac{R}{\gamma - 1}$

13 In the given (V-T) diagram, what is the relation between pressures p_1 and p_2? **[NEET 2013]**



(a) $p_2 = p_1$
(b) $p_2 > p_1$
(c) $p_2 < p_1$
(d) Cannot be predicted

Ans. *(c)*

According to question,

Slope of the graph $\propto \frac{1}{\text{Pressure } p}$

So, $p_2 < p_1$

14 During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its temperature. The ratio of $\frac{C_p}{C_V}$ for the gas is **[NEET 2013]**

(a) $\frac{4}{3}$ (b) 2 (c) $\frac{5}{3}$ (d) $\frac{3}{2}$

Ans. *(d)*

According to question,

$$p \propto T^3 \quad \text{...(i)}$$

$\left(p = \text{pressure}, T = \text{temperature}\right)$

and we know that

$$pV = nRT \text{ and } pV \propto T \quad \text{...(ii)}$$

So, putting Eq. (ii) in (i),

$$p \propto (pV)^3$$

$\Rightarrow p^2V^3 = \text{constant}$

$\Rightarrow pV^{3/2} = \text{constant}$ ...(iii)

$\Rightarrow$ Comparing Eq. (iii) with $pV^{\gamma} = \text{constant}$.

We have $\gamma = 3/2$.

15 At 10°C the value of the density of a fixed mass of an ideal gas divided by its pressure is x. At 110°C this ratio is **[CBSE AIPMT 2008]**

(a) x (b) $\frac{383}{283}x$ (c) $\frac{10}{110}x$ (d) $\frac{283}{383}x$

Ans. *(d)*

Concept Use ideal gas equation to find the ratio between density of a fixed mass of an ideal gas and its pressure.

Ideal gas equation

$$pV = nRT$$

$$\frac{pV}{m} = \frac{1}{M}RT \quad \left(\because n = \frac{m}{M}\right)$$

$$\frac{p}{\rho} = \frac{RT}{M} \quad \left(\because \frac{V}{m} = \frac{1}{\rho}\right)$$

$$\therefore \frac{\rho}{p} \propto \frac{1}{T}$$

Molecular mass M and universal gas constant R remains same for a gas.

So, for two different situations i.e. at two different temperatures and densities

$$\therefore \frac{\rho_1/p_1}{\rho_2/p_2} = \frac{T_2}{T_1} \Rightarrow \frac{x}{(\rho_2/p_2)} = \frac{383\,\text{K}}{283\,\text{K}}$$

$$\Rightarrow \frac{\rho_2}{p_2} = \frac{283}{383}x$$

16 The molar specific heat at constant pressure of an ideal gas is (7/2)R. The ratio of specific heat at constant pressure to that at constant volume is **[CBSE AIPMT 2006]**

(a) 7/5 (b) 8/7 (c) 5/7 (d) 9/7

Ans. *(a)*

We have given molar specific heat at instant pressure

$$C_p = \frac{7}{2}R$$

Mayer's relation can be written as :

Molar specific heat at constant pressure – Molar specific heat at constant volume = Gas constant,

i.e. $C_p - C_V = R \Rightarrow C_V = C_p - R$

$$= \frac{7}{2}R - R = \frac{5}{2}R \left[\because C_p = \frac{7}{2}R\right]$$

Hence, required ratio is

$$\gamma = \frac{C_p}{C_V} = \frac{\left(\frac{7}{2}\right)R}{\left(\frac{5}{2}\right)R} = \frac{7}{5}$$

17 The equation of state for 5 g of oxygen at a pressure p and temperature T, when occupying a volume V, will be **[CBSE AIPMT 2004]**

(a) $pV = \left(\frac{5}{32}\right)RT$ (b) $pV = 5RT$

(c) $pV = \left(\frac{5}{2}\right)RT$ (d) $pV = \left(\frac{5}{16}\right)RT$

Ans. *(a)*

Number of moles,

$$n = \frac{m}{\text{molecular weight}} = \frac{5}{32}$$

As, from ideal gas equation

$$pV = nRT \Rightarrow pV = \frac{5}{32}RT$$

18 An ideal gas at 27°C is compressed adiabatically to $\frac{8}{27}$ of its original volume. The rise in temperature is $\left(\gamma = \frac{5}{3}\right)$ **[CBSE AIPMT 1999]**

(a) 475°C (b) 402°C
(c) 275°C (d) 375°C

Ans. *(d)*

In an adiabatic process

p = pressure

V = volume

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γ = atomicity of gas

pV^{γ} = constant ...(i)

Now from ideal gas equation,

$pV = RT$ (for one mole)

or $p = \frac{RT}{V}$ ...(ii)

(R = gas constant)

From Eqs. (i) and (ii), we have

$$\left(\frac{RT}{V}\right)V^{\gamma} = \text{constant}$$

$$TV^{\gamma-1} = \text{constant} \quad ...(iii)$$

So for two different cases of temperature and volume

So, $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

or $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ ...(iv)

Given, $T_1 = 27°\,C$

$= 27 + 273 = 300\,K$

Given, $\frac{V_2}{V_1} = \frac{8}{27}, \gamma = \frac{5}{3}$

Substituting in Eq. (i), we get

$$\frac{T_2}{300} = \left(\frac{27}{8}\right)^{5/3-1}$$

or $$\frac{T_2}{300} = \left[\left(\frac{3}{2}\right)^3\right]^{2/3}$$

or $$\frac{T_2}{300} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$$

$\therefore \quad T_2 = \frac{9}{4} \times 300 = 675\,K = 402°\,C$

Thus, rise in temperature

$= T_2 - T_1 = 402 - 27 = 375°\,C$

19 A diatomic gas initially at 18°C is compressed adiabatically to one-eight of its original volume. The temperature after compression will be **[CBSE AIPMT 1996]**

(a) 18°C (b) 668.4 K
(c) 395.4°C (d) 144°C

Ans. *(b)*

According to adiabatic process the relation between temperature and volume is given by

$$TV^{\gamma-1} = \text{constant}$$

So, for two different cases

$\therefore \quad T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$ ...(i)

Given, initial temperature

$T_1 = 18°\,C = 291\,K$

Let initial volume $V_1 = V$

and final volume $V_2 = \left(\frac{1}{8}\right)V$

Putting these values in Eq. (i)

$$T_2 = 291\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 291\left(\frac{V}{\left(\frac{1}{8}\right)V}\right)^{7/5-1}$$

($\gamma = \frac{7}{5}$ for diatomic gas)

$= 291 \times 2.297 = 668.4\,K$

20 The pressure of a gas is raised from 27°C to 927°C. The root mean square speed **[CBSE AIPMT 1994]**

(a) is $\sqrt{\left(\frac{927}{27}\right)}$ times the earlier value

(b) remains the same

(c) gets halved

(d) gets doubled

Ans. *(d)*

RMS speed is defined as the square root of the mean of the squares of the random velocities of the individual molecules of a gas. From Maxwellian distribution law, RMS speed is given by

$$c_{rms} = \sqrt{\left(\frac{3kT}{m}\right)}$$

$\Rightarrow \quad c_{rms} \propto \sqrt{T}$

For two different cases i.e. at two different temperatures

$\therefore \quad \frac{(c_{rms})_1}{(c_{rms})_2} = \sqrt{\frac{T_1}{T_2}}$

Here, $T_1 = 27°C = 300\,K$

$T_2 = 927°C = 1200\,K$

$\therefore \quad \frac{(c_{rms})_1}{(c_{rms})_2} = \sqrt{\frac{300}{1200}} = \frac{1}{2}$

$\Rightarrow \quad (c_{rms})_2 = 2(c_{rms})_1$

Hence, root mean square speed will be doubled.

21 Relation between pressure (p) and energy (E) of a gas is **[CBSE AIPMT 1991]**

(a) $p = \frac{2}{3}E$ (b) $p = \frac{1}{3}E$
(c) $p = \frac{3}{2}E$ (d) $p = 3E$

Ans. *(a)*

Pressure exerted by gas molecules is

$$p = \frac{1}{3}\rho\bar{v}^2 \quad ...(i)$$

where, ρ = density of gas

$\bar{v}$ = average velocity of gas molecules

or $p = \frac{2}{3}n \cdot \frac{1}{2}m\bar{v}^2$ ($\because \rho = mn$)

Now, $\frac{1}{2}m\bar{v}^2$ = average kinetic energy of a gas molecule ($\overline{KE}$)

Therefore, $p = \frac{2}{3}n\,\overline{KE}$

If N is total number of gas molecules in volume V, then

No of gas molecules per unit volume

$$n = \frac{N}{V}$$

$\therefore \quad p = \frac{2}{3}\cdot\frac{N}{V}\left(\frac{1}{2}m\bar{v}^2\right)$

or $pV = \frac{2}{3}N(\overline{KE}) \quad \left[KE = \frac{1}{2}m\bar{v}^2\right]$

Also, from Eq. (i),

$$p = \frac{2}{3}\cdot\frac{1}{2}\rho\bar{v}^2$$

Now, $\frac{1}{2}\rho\bar{v}^2$ = average kinetic energy of the gas per unit volume.

Therefore, $p = \frac{2}{3}E$

22 Three containers of the same volume contain three different gases. The masses of the molecules are m_1, m_2 and m_3 and the number of molecules in their respective containers are N_1, N_2 and N_3. The gas pressure in the containers are p_1, p_2 and p_3 respectively. All the gases are now mixed and put in one of these containers. The pressure p of the mixture will be **[CBSE AIPMT 1991]**

(a) $p < (p_1 + p_2 + p_3)$
(b) $p = \frac{p_1 + p_2 + p_3}{3}$
(c) $p = p_1 + p_2 + p_3$
(d) $p > (p_1 + p_2 + p_3)$

Ans. *(c)*

According to Dalton's law of partial pressure, the total pressure exerted by a mixture of gases, which do not interact with each other, is equal to sum of the partial pressures which each would exert, if alone occupied the same volume at the given temperature. When gases are put in one container, then pressure p of the mixture will be

$$p = p_1 + p_2 + p_3$$

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23 One mole of an ideal gas requires 207 J heat to rise the temperature by 10 K when heated at constant pressure. If the same gas is heated at constant volume to raise the temperature by the same 10 K, the heat required is (Given the gas constant $R = 8.3$ J/mol-K) **[CBSE AIPMT 1990]**

(a) 198.7 J (b) 29 J
(c) 215.3 J (d) 124 J

Ans. *(d)*

Molar specific heat of a substance is defined as the amount of heat required to raise the temperature of one gram mole of the substance through a unit degree.

As $(dQ)_p = \mu C_p dT$ ...(i)

(At constant pressure)

and $(dQ)_V = \mu C_V dT$ ...(ii)

(At constant volume)

Given, $(dQ)_p = 207$ J

$R = 8.3$ J/mol-K

$dT = 10$ K

Putting value in Eq. (i)

$207 = 1 \times C_p \times 10$

$\therefore \quad C_p = 20.7$ J/kg

As $C_p - C_V = R = 8.3$

$C_V = 20.7 - 8.3 = 12.4$ J

$\therefore \quad (dQ)_V = 1 \times 12.4 \times 10$

$= 124$ J

24 For a certain gas the ratio of specific heats is given to be $\gamma = 1.5$, for this gas **[CBSE AIPMT 1990]**

(a) $C_V = \frac{3R}{J}$ (b) $C_p = \frac{3R}{J}$
(c) $C_p = \frac{5R}{J}$ (d) $C_p = \frac{5R}{J}$

Ans. *(b)*

Given, $\gamma = \frac{C_p}{C_V} = 1.5 = \frac{3}{2}$

$\therefore \quad C_V = \frac{2}{3} C_p$

Again from Mayer's formula

$C_p - C_V = \frac{R}{J}$

$\therefore \quad C_p - \frac{2}{3} C_p = \frac{R}{J}$

$\Rightarrow \quad \frac{C_p}{3} = \frac{R}{J}$

$\Rightarrow \quad C_p = \frac{3R}{J}$

25 For hydrogen gas $C_p - C_V = a$ and for oxygen gas $C_p - C_V = b$, so the relation between a and b is given by **[CBSE AIPMT 1991]**

(a) $a = 16b$
(b) $16b = a$
(c) $a = 4b$
(d) $a = b$

Ans. *(d)*

Both hydrogen and oxygen are diatomic gases and $C_p - C_V = R$ is same for all gases, hence $a = b$, provided C_p and C_V are gram molar specific heats.

If it was the case of specific heat of 1 g

$C_p - C_V = r = \frac{R}{m}$

$\therefore \quad C_p - C_V = \frac{R}{2}$ (for H, $\frac{R}{2} = a$)

$C_p - C_V = \frac{R}{32}$ (for O_2, $\frac{R}{32} = b$)

$R = 2a = 32b$

$a = 16b$

26 According to kinetic theory of gases, at absolute zero temperature **[CBSE AIPMT 1990]**

(a) water freezes
(b) liquid helium freezes
(c) molecular motion stops
(d) liquid hydrogen freezes

Ans. *(c)*

According to kinetic theory of gases, the pressure p exerted by one mole of an ideal gas is given by

$p = \frac{1}{3} \frac{M}{V} c^2$ or $pV = \frac{1}{3} Mc^2$

or $\frac{1}{3} Mc^2 = RT$ ...(i)

where c is root mean square velocity of gas.

From Eq. (i), when $T = 0$, $c = 0$

Hence, absolute zero of temperature may be defined as that temperature at which root mean square velocity of the gas molecules reduces to zero. It means molecular motion ceases at absolute zero.

27 At 27°C a gas is compressed suddenly such that its pressure becomes $\left(\frac{1}{8}\right)$ of original pressure. Final temperature will be $\left(\gamma = \frac{5}{3}\right)$ **[CBSE AIPMT 1989]**

(a) 420 K (b) 300 K
(c) –142° C (d) 327 K

Ans. *(c)*

The adiabatic relation between p and V for a perfect gas is

$pV^\gamma = k$ (a constant) ...(i)

Again from standard gas equation

$pV = nRT \Rightarrow V = \frac{RT}{p}$

Putting in Eq. (i), we get

$p \frac{R^\gamma T^\gamma}{p^\gamma} = k$

or $p^{1-\gamma} T^\gamma = \frac{k}{R^\gamma} =$ another constant

i.e. $p^{1-\gamma} T^\gamma = constant$

Comparing two different situations,

$p_1^{1-\gamma} T_1^\gamma = p_2^{1-\gamma} T_2^\gamma$

Here, $p_2 = \left(\frac{1}{8}\right) p_1$

$T_1 = 27°\text{C} = 273 + 27 = 300$ K

$T_2 = ?, \gamma = \frac{5}{3}$

$\therefore \quad \left(\frac{T_2}{T_1}\right)^\gamma = \left(\frac{p_1}{p_2}\right)^{1-\gamma}$

or $\left(\frac{T_2}{300}\right)^{5/3} = (8)^{1-5/3} = (8)^{-2/3}$

$\Rightarrow \quad T_2 = 130.6$ K

$\therefore \quad T_2 = -142°\text{C}$

28 At constant volume temperature is increased, then **[CBSE AIPMT 1989]**

(a) collision on walls will be less
(b) number of collisions per unit time will increase
(c) collisions will be in straight lines
(d) collisions will not change

Ans. *(b)*

On raising the temperature, the average velocity of the gas molecules increases. As a result of which more molecules collide with the walls or number of collisions per unit time will increase.

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TOPIC 2

Degree of Freedom and Law of Equipartition of Energy

29 Match Column I with Column II and choose the correct match from the given choices. **[NEET 2021]**

	Column I		Column II
A.	Root mean square of gas molecules	1.	$\frac{1}{3}nm\bar{v}^2$
B.	Pressure exerted by ideal gas	2.	$\sqrt{\frac{3RT}{M}}$
C.	Average kinetic energy of a molecule	3.	$\frac{5}{2}RT$
D.	Total internal energy of 1 mole of a diatomic gas	4.	$\frac{3}{2}k_BT$

Codes

	A	B	C	D
(a)	3	1	4	2
(b)	2	3	4	1
(c)	2	1	4	3
(d)	3	2	1	4

Ans. *(c)*

We know that, the rms speed of the gas molecules,

$$v_{rms} = \sqrt{3RT/M}$$

Here, T is the temperature of the gas,

R is the universal gas constant,

M is the molar mass of the gas.

Pressure exerted by an ideal gas,

$$p = \frac{1}{3}nm\bar{v}^2$$

Here, n is the number of moles,

m is the mass of the gas,

$\bar{v}$ is the average speed of the gas molecules.

The average kinetic energy of a molecule,

$$KE_{av} = \frac{3}{2}k_BT$$

Here, k_B is the Boltzmann constant,

T is the temperature of the gas.

For diatomic gas, degree of freedom, $f = 5$

As, total internal energy of 1 mole of diatomic gas,

$$\Delta U = \frac{nfRT}{2}$$

$$\Rightarrow \quad \Delta U = \frac{1(5)RT}{2} \Rightarrow \Delta U = \frac{5RT}{2}$$

The correct match is A $\rightarrow$ 2, B $\rightarrow$ 1, C $\rightarrow$ 4 and D $\rightarrow$ 3.

30 The average thermal energy for a monoatomic gas is (where, k_B is Boltzmann constant and T is absolute temperature.) **[NEET (Sep.) 2020]**

(a) $\frac{3}{2}k_BT$ (b) $\frac{5}{2}k_BT$ (c) $\frac{7}{2}k_BT$ (d) $\frac{1}{2}k_BT$

Ans. *(a)*

The average thermal energy of a system with degree of freedom f is equals to its average energy, which is given as

$$= \frac{f}{2}k_B \cdot T$$

For monoatomic gas, $f = 3$

$\therefore$ Average thermal energy $= \frac{3}{2}k_B \cdot T$

Hence, correct option is (a).

31 The value of $\gamma\left(=\frac{C_p}{C_V}\right)$, for hydrogen, helium and another ideal diatomic gas X (whose molecules are not rigid but have an additional vibrational mode), are respectively equal to **[NEET (Odisha) 2019]**

(a) $\frac{7}{5}, \frac{5}{3}, \frac{9}{7}$ (b) $\frac{5}{3}, \frac{7}{5}, \frac{9}{7}$

(c) $\frac{5}{3}, \frac{7}{5}, \frac{7}{5}$ (d) $\frac{7}{5}, \frac{5}{3}, \frac{7}{5}$

Ans. *(a)*

The poisson's ratio,

$$\gamma = \frac{C_P}{C_V} \qquad ...(i)$$

where, C_p = molar heat capacity constant pressure

and C_V = molar heat capacity at constant volume

Also, $C_p = C_V + R$ (from Mayer's relation)

$C_V = \frac{f}{2}R$ (where, f = degree of freedom)

$$\Rightarrow \quad C_p = \left(\frac{f}{2} + 1\right)R$$

So, Eq. (i) becomes,

$$\Rightarrow \quad \gamma = 1 + \frac{2}{f}$$

For hydrogen gas, which is diatomic, the degree of freedom is 5 (3 translational, 2 rotational).

$$\therefore \quad \gamma = 1 + \frac{2}{5} = \frac{7}{5}$$

For helium gas, which is monoatomic, the degree of freedom is 3 (3 translational only).

$$\therefore \quad \gamma = 1 + \frac{2}{3} = \frac{5}{3}$$

The diatomic gas X also have vibrational motion, so degree of freedom is 7 (3 translational, 2 rotational and 2 vibrational).

$$\therefore \quad \gamma = 1 + \frac{2}{7} = \frac{9}{7}$$

32 A gas mixture consists of 2 moles of O_2 and 4 moles of Ar at temperature T. Neglecting all vibrational modes, the total internal energy of the system is **[NEET 2017]**

(a) $4RT$ (b) $15RT$

(c) $9RT$ (d) $11RT$

Ans. *(d)*

Total internal energy of system = Internal energy of oxygen molecules + Internal energy of argon molecules

$$= \frac{f_1}{2}n_1RT + \frac{f_2}{2}n_2RT = \frac{5}{2} \times 2RT + \frac{3}{2} \times 4RT$$

$$= 11RT$$

33 One mole of an ideal monatomic gas undergoes a process described by the equation pV^3 = constant. The heat capacity of the gas during this process is **[NEET 2016]**

(a) $\frac{3}{2}R$ (b) $\frac{5}{2}R$ (c) $2R$ (d) R

Ans. *(d)*

As we know that for polytropic process of index α specific heat capacity

$$= C_V + \frac{R}{1-\alpha}$$

$\because$ Process, pV^3 = constant $\Rightarrow \alpha = 3$

$$\therefore \quad C = C_V + \frac{R}{1-\alpha} = \frac{fR}{2} + \frac{R}{1-3}$$

where, $C_V = \frac{fR}{2} = \frac{3R}{2}$

For monatomic gas, $f = 3 = \frac{3R}{2}$

$$\Rightarrow \qquad C = \frac{3R}{2} - \frac{R}{2} = R$$

34 The amount of heat energy required to raise the temperature of 1 g of helium at NTP, from T_1 K to T_2 K is **[NEET 2013]**

(a) $\frac{3}{8}N_aK_B(T_2 - T_1)$ (b) $\frac{3}{2}N_aK_B(T_2 - T_1)$

(c) $\frac{3}{4}N_aK_B(T_2 - T_1)$ (d) $\frac{3}{4}N_aK_B\left(\frac{T_2}{T_1}\right)$

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Ans. *(a)*

We know that, $Q = \frac{F}{2} nR\,\Delta T$

$\therefore$ Amount of heat required,

$Q = \frac{3}{2} \times \frac{1}{4} \times K_B N_a \Delta T = \frac{3}{8} N_a K_B (T_2 - T_1)$

35 The ratio of the specific heats $\frac{C_p}{C_V} = \gamma$ in terms of degrees of freedom (n) is given by **[CBSE AIPMT 2015]**

(a) $\left(1+\frac{1}{n}\right)$ (b) $\left(1+\frac{n}{3}\right)$

(c) $\left(1+\frac{2}{n}\right)$ (d) $\left(1+\frac{n}{2}\right)$

Ans. *(c)*

The specific heat of gas at constant volume in terms of degree of freedom n is

$$C_V = \frac{n}{2} R$$

Also $C_p - C_V = R$

So $C_p = \frac{n}{2} R + R = R\left(1+\frac{n}{2}\right)$

Now $\gamma = \frac{C_p}{C_V} = \frac{R\left(1+\frac{n}{2}\right)}{\frac{n}{2}R} = \frac{2}{n} + 1$

36 The gases carbon-monoxide (CO) and nitrogen at the same temperature have kinetic energies E_1 and E_2 respectively. Then **[CBSE AIPMT 2000]**

(a) $E_1 = E_2$

(b) $E_1 > E_2$

(c) $E_1 < E_2$

(d) E_1 and E_2 cannot be compared

Ans. *(a)*

The gases carbon-monoxide (CO) and nitrogen (N_2) are diatomic, so both have equal kinetic energy $\frac{5}{2} kT$, i.e. $E_1 = E_2$.

37 The degrees of freedom of a molecule of a triatomic gas are **[CBSE AIPMT 1999]**

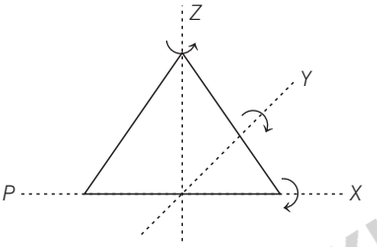
(a) 2 (b) 4

(c) 6 (d) 8

Ans. *(c)*

The molecule of a triatomic gas has a tendency of rotating about any of three coordinate axes. So, it has 6 degrees of freedom, 3 translational and 3 rotational. At high enough temperature a triatomic molecule has 2 vibrational degree of freedom. But as temperature requirement is not given, so we answer simply by assuming triatomic gas molecule at room temperature.

Thus, $f = 6$



(3 translational + 3 rotational) at room temperature.

38 The number of translational degree of freedom for a diatomic gas is **[CBSE AIPMT 1993]**

(a) 2 (b) 3

(c) 5 (d) 6

Ans. *(b)*

Number of degree of freedom of a dynamical system is obtained by subtracting the number of independent relations from the total number of coordinates required to specify the positions of constituent particles of the system.

If A = number of particles in the system,

R = number of independent relations among the particles,

N = number of degree of freedom of the system, then

$$N = 3A - R$$

Each monoatomic, diatomic and triatomic gas has three translatory degree of freedom.

39 If for a gas, $\frac{R}{C_V} = 0.67$, this gas is made up of molecules which are **[CBSE AIPMT 1992]**

(a) diatomic

(b) mixture of diatomic and polyatomic molecules

(c) monoatomic

(d) polyatomic

Ans. *(c)*

$$C_V = \frac{R}{0.67} \approx 1.5\,R = \frac{3}{2} R$$

This is the case of monoatomic gases.

when $C_V = \frac{3}{2} R$

40 A polyatomic gas with n degrees of freedom has a mean energy per molecule given by **[CBSE AIPMT 1989]**

(a) $\frac{nkT}{N}$ (b) $\frac{nkT}{2N}$

(c) $\frac{nkT}{2}$ (d) $\frac{3kT}{2}$

Ans. *(c)*

Concept If there is sudden compression without exchange of heat the process will be adiabatic.

According to law of equipartition of energy for any dynamical system in thermal equilibrium, the total energy is distributed equally amongst all the degrees of freedom and the energy associated with each molecule per degree of freedom is $\frac{1}{2} kT$. For a polyatomic gas with n degrees of freedom the mean energy per molecule $= \frac{1}{2} nkT$.

K = Boltzmann constant

n = degree of freedom

T = Temperature

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13
Oscillations

TOPIC 1
Simple Harmonic Motion

01 A body is executing simple harmonic motion with frequency n, the frequency of its potential energy is **[NEET 2021]**

(a) n (b) $2n$ (c) $3n$ (d) $4n$

Ans. *(b)*

In simple harmonic motion, both kinetic energy and potential energy attains their maximum value two times in one complete oscillation. Hence, frequency of kinetic energy and potential energy is 2 for one complete oscillation. So, the frequency of the potential energy of a body executing SHM with frequency n is $2n$.

02 Identify the function which represents a periodic motion. **[NEET (Oct.) 2020]**

(a) $e^{\omega t}$ (b) $\log_e(\omega t)$

(c) $\sin\omega t + \cos\omega t$ (d) $e^{-\omega t}$

Ans. *(c)*

$\sin\omega t$ and $\cos\omega t$, both are periodic function of period $\frac{2\pi}{\omega}$.

We know that, sum of two periodic functions is also a periodic function, hence, $\sin\omega t + \cos\omega t$ represents periodic motion.

03 The phase difference between displacement and acceleration of a particle in a simple harmonic motion is **[NEET (Sep.) 2020]**

(a) $\frac{3\pi}{2}$ rad (b) $\frac{\pi}{2}$ rad

(c) zero (d) π rad

Ans. *(d)*

In SHM, equation of displacement of a particle is $y = a\sin\omega t$

and equation of acceleration of a particle is

$$A = a\omega^2 \sin\omega t = a\omega^2 \sin(\omega t + \pi)$$

$\therefore$ Phase difference between displacement and acceleration of a particle is

$$= (\omega t + \pi) - \omega t = \pi \text{ rad}$$

Hence, correct option is (d).

04 The distance covered by a particle undergoing SHM in one time period is (amplitude = A) **[NEET (Odisha) 2019]**

(a) zero (b) A

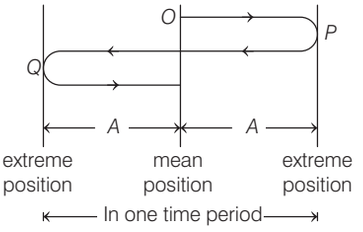
(c) 2A (d) 4A

Ans. *(d)*

In a simple harmonic motion (SHM) the particle oscillates about its mean position on a straight line.

The particle moves from its mean position (O) to an extreme position (P) and then return to its mean position covering same distance of A.

Then by the conservative force, it is moved in opposite direction to a point Q by distance A and then back to mean position covering a distance of A. This comprises of one time period as shown below



Hence, in one time period it covers a distance of

$$x = OP + PO + OQ + QO$$
$$= A + A + A + A = 4A$$

05 Average velocity of a particle executing SHM in one complete vibration is **[NEET (National) 2019]**

(a) $A\omega$ (b) $\frac{A\omega^2}{2}$

(c) zero (d) $\frac{A\omega}{2}$

Ans. *(c)*

The average velocity of a particle executing simple harmonic motion (SHM) is

$$v_{av} = \frac{\text{Total displacement}}{\text{Time interval}} = \frac{x_f - x_i}{T}$$

where, x_f and x_i are the initial and final position of the particle executing SHM.

As, in vibrational motion, the particle executes SHM about its mean position. So, after one complete vibration of the particle, it will reaches its initial position, i.e.

Displacement, $x_f - x_i = 0$

$\therefore \quad v_{av} = \frac{0}{T}$

Hence, the average velocity is zero.

06 The displacement of a particle executing simple harmonic motion is given by

$$y = A_0 + A\sin\omega t + B\cos\omega t$$

Then the amplitude of its oscillation is given by **[NEET (National) 2019]**

(a) $\sqrt{A^2 + B^2}$ (b) $\sqrt{A_0^2 + (A+B)^2}$

(c) $A + B$ (d) $A_0 + \sqrt{A^2 + B^2}$

Ans. *(a)*

The displacement of given particle is

$$y = A_0 + A\sin\omega t + B\cos\omega t \quad \ldots(i)$$

The general equation of SHM can be given as

$$x = a\sin\omega t + b\cos\omega t \quad \ldots(ii)$$

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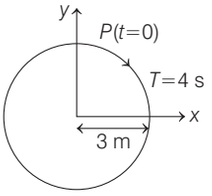
So, from Eqs. (i) and (ii), we can say that A_0 be the value of mean position, at which $y = 0$.

$\therefore$ Amplitude, $R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$

As two function sine and cosine have phase shift to 90°.

$\therefore R = \sqrt{A^2 + B^2}$ $[\because \cos 90° = 0]$

07 The radius of circle, the period of revolution, initial position and sense of revolution are indicated in the below fig. **[NEET (National) 2019]**



y-projection of the radius vector of rotating particle P is

(a) $y(t) = 4\sin\left(\frac{\pi t}{2}\right)$, where y in m

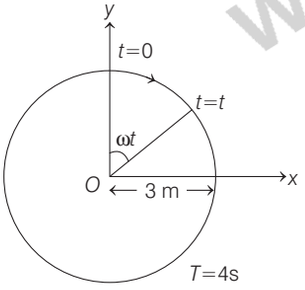
(b) $y(t) = 3\cos\left(\frac{3\pi t}{2}\right)$, where y in m

(c) $y(t) = 3\cos\left(\frac{\pi t}{2}\right)$, where y in m

(d) $y(t) = -3\cos 2\pi t$, where y in m

Ans. *(c)*

Let O be the centre of circle, then at $t = 0$, the displacement y is maximum and have value 3 m.



As, the general equation of displacement of a particle will be in the form

$y = A\cos\omega t$

Here, $A = 3$ m

Then, $\omega = \frac{2\pi}{T} = \frac{2\pi}{4}$ $[\text{given}, T = 4\text{ s}]$

$= \frac{\pi}{2}$

$\therefore$ $y = 3\cos\left(\frac{\pi}{2}t\right)$ (in metre)

08 A particle executes linear simple harmonic motion with an amplitude of 3 cm. When the particle is at 2 cm from the mean position, the magnitude of its velocity is equal to that of its acceleration. Then, its time period in seconds is **[NEET 2017]**

(a) $\frac{\sqrt{5}}{\pi}$ (b) $\frac{\sqrt{5}}{2\pi}$

(c) $\frac{4\pi}{\sqrt{5}}$ (d) $\frac{2\pi}{\sqrt{3}}$

Ans. *(c)*

Thinking Process Magnitude of velocity of particle when it is at displacement x from mean position

$= \omega\sqrt{A^2 - x^2}$

Also, magnitude of acceleration of particle in SHM

$= \omega^2 x$

Given, when $x = 2$ cm

$|\mathbf{v}| = |\mathbf{a}| \Rightarrow \omega\sqrt{A^2 - x^2} = \omega^2 x$

$\Rightarrow$ $\omega = \frac{\sqrt{A^2 - x^2}}{x} = \frac{\sqrt{9-4}}{2}$

$\Rightarrow$ Angular velocity $\omega = \frac{\sqrt{5}}{2}$

$\therefore$ Time period of motion

$T = \frac{2\pi}{\omega} = \frac{4\pi}{\sqrt{5}}$ s

09 When two displacements represented by $y_1 = a\sin(\omega t)$ and $y_2 = b\cos(\omega t)$ are superimposed, the motion is **[CBSE AIPMT 2015]**

(a) not a simple harmonic

(b) simple harmonic with amplitude $\frac{a}{b}$

(c) simple harmonic with amplitude $\sqrt{a^2 + b^2}$

(d) simple harmonic with amplitude $\frac{(a+b)}{2}$

Ans. *(c)*

Given, $y_1 = a\sin\omega t$

$y_2 = b\cos\omega t = b\sin\left(\omega t + \frac{\pi}{2}\right)$

The resultant displacement is given by

$y = y_1 + y_2 = \sqrt{a^2 + b^2}\sin(\omega t + \phi)$

Hence, the motion of superimposed wave is simple harmonic with amplitude $\sqrt{a^2 + b^2}$.

10 A particle is executing SHM along a straight line. Its velocities at distances x_1 and x_2 from the mean position are v_1 and v_2, respectively. Its time period is **[CBSE AIPMT 2015]**

(a) $2\pi\sqrt{\frac{x_1^2 + x_2^2}{v_1^2 + v_2^2}}$ (b) $2\pi\sqrt{\frac{x_2^2 - x_1^2}{v_1^2 - v_2^2}}$

(c) $2\pi\sqrt{\frac{v_1^2 + v_2^2}{x_1^2 + x_2^2}}$ (d) $2\pi\sqrt{\frac{v_1^2 - v_2^2}{x_1^2 - x_2^2}}$

Ans. *(b)*

Let A be the amplitude of oscillation, then

$v_1^2 = \omega^2(A^2 - x_1^2)$ ...(i)

$v_2^2 = \omega^2(A^2 - x^2)$ ...(ii)

Subtracting Eq. (ii) from Eq. (i), we get

$v_1^2 - v_2^2 = \omega^2(x_2^2 - x_1^2)$

$\Rightarrow$ $\omega = \sqrt{\frac{v_1^2 - v_2^2}{x_2^2 - x_1^2}} \Rightarrow \frac{2\pi}{T} = \sqrt{\frac{v_1^2 - v_2^2}{x_2^2 - x_1^2}}$

$\Rightarrow$ $T = 2\pi\sqrt{\frac{x_2^2 - x_1^2}{v_1^2 - v_2^2}}$

11 A particle is executing a simple harmonic motion. Its maximum acceleration is α and maximum velocity is β. Then, its time period of vibration will be **[CBSE AIPMT 2015]**

(a) $\frac{\beta^2}{\alpha^2}$ (b) $\frac{\alpha}{\beta}$ (c) $\frac{\beta^2}{\alpha}$ (d) $\frac{2\pi\beta}{\alpha}$

Ans. *(d)*

For a particle executing SHM, we have maximum acceleration,

$\alpha = A\omega^2$ ...(i)

where, A is maximum amplitude and ω is angular velocity of a particle.

Maximum velocity, $\beta = A\omega$ ...(ii)

Dividing Eq. (i) by Eq. (ii), we get

$\frac{\alpha}{\beta} = \frac{A\omega^2}{A\omega} \Rightarrow \frac{\alpha}{\beta} = \omega = \frac{2\pi}{T}$

i.e. $T = \frac{2\pi\beta}{\alpha}$

Thus, its time period of vibration, $T = \frac{2\pi\beta}{\alpha}$

12 The oscillation of a body on a smooth horizontal surface is represented by the equation,

$X = A\cos(\omega t)$

where, X = displacement at time t

ω = frequency of oscillation

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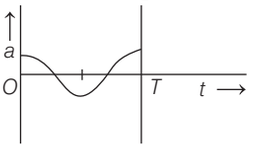
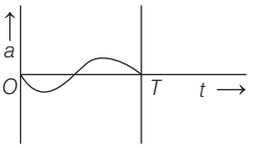
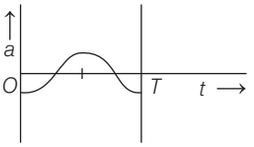
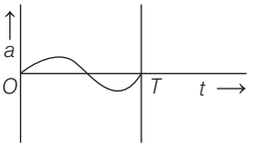
Which one of the following graphs shows
correctly the variation a with t?
[CBSE AIPMT 2014]

(a) 

(b) 

(c) 

(d) 

Here, a = acceleration at time t
T = Time period

Ans. *(c)*

As, $x = A\cos\omega t$

$\therefore\ v = \frac{dx}{dt} = -A\omega\sin\omega t$ ...(i)

and $a = \frac{d^2x}{dt^2} = -A\omega^2\cos\omega t$ ...(ii)

We can find the correct graph by putting different values of t in Eq. (ii).

At $t = 0$, $a = -A\omega^2$

At $t = \frac{T}{4}$, $a = -A\omega^2\cos\left(\frac{2\pi}{T}\times\frac{T}{4}\right) = 0$

At $t = \frac{T}{2}$, $a = -A\omega^2\cos\left(\frac{2\pi}{T}\times\frac{T}{2}\right)$

$= -A\omega^2\cos\pi = +A\omega^2$

At $t = \frac{3T}{4}$, $a = -A\omega^2\cos\left(\frac{2\pi}{T}\times\frac{3T}{4}\right) = 0$

At $t = T$, $a = -A\omega^2\cos\left(\frac{2\pi}{T}\times T\right) = -A\omega^2$

This condition is represented by graph in option (c).

13 Out of the following functions representing motion of a particle which represents SHM?
[CBSE AIPMT 2011]

I. $y = \sin\omega t - \cos\omega t$

II. $y = \sin^3\omega t$

III. $y = 5\cos\left(\frac{3\pi}{4} - 3\omega t\right)$

IV. $y = 1 + \omega t + \omega^2 t^2$

(a) Only (IV) does not represent SHM
(b) (I) and (III)
(c) (I) and (II)
(d) Only (I)

Ans. *(b)*

For a simple harmonic motion,

$$a \propto \frac{d^2y}{dt^2} \propto -y$$

Hence, equations $y = \sin\omega t - \cos\omega t$ and $y = 5\cos\left(\frac{3\pi}{4} - 3\omega t\right)$ are satisfying this condition and equation $y = 1 + \omega t + \omega^2 t^2$ is not periodic and $y = \sin^3\omega t$ is periodic but not simple hormonic motion.

14 The displacement of a particle along the x-axis is given by $x = a\sin^2\omega t$. The motion of the particle corresponds to
[CBSE AIPMT 2010]

(a) simple harmonic motion of frequency ω/π
(b) simple harmonic motion of frequency $3\omega/2\pi$
(c) non-simple harmonic motion
(d) simple harmonic motion of frequency $\omega/2\pi$

Ans. *(c)*

For a particle executing SHM

Acceleration $(a) \propto -\omega^2$ displacement (x) ...(i)

Given $x = a\sin^2\omega t$ ...(ii)

Differentiating the above equation w.r.t, we get $\frac{dx}{dt} = 2a\omega(\sin\omega t)(\cos\omega t)$

Again differentiating, we get

$$\frac{d^2x}{dt^2} = a = 2a\omega^2[\cos^2\omega t - \sin^2\omega t]$$

$$= 2a\omega^2\cos 2\omega t$$

The given equation does not satisfy the condition for SHM [Eq. (i)]. Therefore, motion is not simple harmonic.

15 Which one of the following equations of motion represents simple harmonic motion ?
[CBSE AIPMT 2009]

(a) Acceleration $= -k_0x + k_1x^2$
(b) Acceleration $= -k(x + a)$
(c) Acceleration $= k(x + a)$
(d) Acceleration $= kx$
(where, k, k_0, k_1 and a are all positive.)

Ans. *(b)*

As we know that, the condition for a body executing SHM is $F = -kx$

So, $a = \frac{F}{m} = -\frac{k}{m}x$

or $a = -\omega^2 x$

Acceleration $\propto -$(displacement)

$$A \propto -y$$
$$A = -\omega^2 y$$
$$A = -\frac{k}{m}y$$
$$A = -ky$$

Here, $y = x + a$

$\therefore$ Acceleration $= -k(x + a)$

16 Two simple harmonic motions of angular frequency 100 rad s^{-1} and 1000 rad s^{-1} have the same displacement amplitude. The ratio of their maximum accelerations is
[CBSE AIPMT 2008]

(a) 1:10 (b) $1:10^2$
(c) $1:10^3$ (d) $1:10^4$

Ans. *(b)*

Maximum acceleration of body executing SHM is given by

$\alpha_{max} = \omega^2 a$

So, for two different cases,

$$\frac{\alpha_{max_1}}{\alpha_{max_2}} = \frac{\omega_1^2}{\omega_2^2} \quad (\because a \text{ is same})$$

$$= \frac{(100)^2}{(1000)^2} = \frac{1}{10^2}$$

17 A point performs simple harmonic oscillation of period T and the equation of motion is given by $x = a\sin\left(\omega t + \frac{\pi}{6}\right)$. After the elapse of what fraction of the time period, the velocity of the point will be equal to half of its maximum velocity ?
[CBSE AIPMT 2008]

(a) $\frac{T}{8}$ (b) $\frac{T}{6}$
(c) $\frac{T}{3}$ (d) $\frac{T}{12}$

Ans. *(d)*

According to the question, equation of motion of SHM is

$$x = a\sin\left(\omega t + \frac{\pi}{6}\right)$$

velocity of body is given by

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$$v=\frac{dx}{dt}=a\omega\cos\left(\omega t+\frac{\pi}{6}\right)$$

$$\frac{a\omega}{2}=a\omega\cos\left(\omega t+\frac{\pi}{6}\right)$$

$$\frac{1}{2}=\cos\left(\omega t+\frac{\pi}{6}\right)$$

$$\omega t+\frac{\pi}{6}=\frac{\pi}{3} \qquad \left[\because \cos\frac{\pi}{3}=\frac{1}{2}\right]$$

$$\Rightarrow \quad \omega t=\frac{\pi}{6}$$

$$\frac{2\pi}{T}t=\frac{\pi}{6} \Rightarrow t=\frac{T}{12}$$

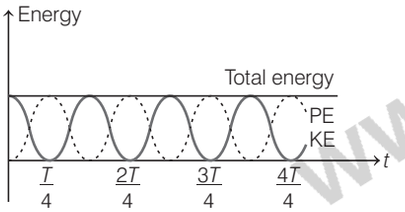
18 The particle executing simple harmonic motion has a kinetic energy $K_0\cos^2\omega t$. The maximum values of the potential energy and the total energy are respectively **[CBSE AIPMT 2007]**

(a) 0 and $2K_0$ (b) $\frac{K_0}{2}$ and K_0

(c) K_0 and $2K_0$ (d) K_0 and K_0

Ans. *(d)*

In simple harmonic motion, the total energy of the particle is constant at all instants which is totally kinetic when particle is passing through the mean position and is totally potential when particle is passing through the extreme position.



The variation of PE and KE with time is shown in figure, by dotted parabolic curve and solid parabolic curve respectively.

Figure indicates that maximum values of total energy, KE and PE of SHM are equal.

Now, $KE=K_0\cos^2\omega t$

$\therefore$ $KE_{max}=K_0$

So, $PE_{max}=K_0$

and $(E)_{Total}=K_0$

19 A particle executes simple harmonic oscillation with an amplitude a. The period of oscillation is T. The minimum time taken by the particle to travel half of the amplitude from the equilibrium position is **[CBSE AIPMT 2007]**

(a) $\frac{T}{4}$ (b) $\frac{T}{8}$ (c) $\frac{T}{12}$ (d) $\frac{T}{2}$

Ans. *(c)*

Let displacement equation of particle executing SHM is

$$x=a\sin\omega t$$

As particle travels half of the amplitude from the equilibrium position, so

$$x=\frac{a}{2}$$

Therefore, $\frac{a}{2}=a\sin\omega t$

or $\sin\omega t=\frac{1}{2}=\sin\frac{\pi}{6}$

or $\omega t=\frac{\pi}{6}$ or $t=\frac{\pi}{6\omega}$

or $t=\frac{\pi}{6\left(\frac{2\pi}{T}\right)} \qquad \left(\text{as, } \omega=\frac{2\pi}{T}\right)$

or $t=\frac{T}{12}$

Hence, the particle travels half of the amplitude from the equilibrium in $\frac{T}{12}$ s.

20 A particle executing simple harmonic motion of amplitude 5 cm has maximum speed of 31.4 cm/s. The frequency of its oscillation is **[CBSE AIPMT 2005]**

(a) 3 Hz (b) 2 Hz

(c) 4 Hz (d) 1 Hz

Ans. *(d)*

Maximum speed of a particle executing SHM is given by,

$$v_{max}=a\,\omega=a\,(2\pi n) \Rightarrow n=\frac{v_{max}}{2\pi a}$$

where, a = amplitude of oscillation

n = frequency of oscillation

Here, $v_{max}=31.4$ cm/s, $a=5$ cm

Substituting, the given values, we have

$$n=\frac{31.4}{2\times3.14\times5}=1\text{ Hz}$$

21 Which one of the following statements is true for the speed v and the acceleration α of a particle executing simple harmonic motion? **[CBSE AIPMT 2004]**

(a) When v is maximum, α is maximum

(b) Value of α is zero, whatever may be the value of v

(c) When v is zero, α is zero

(d) When v is maximum, α is zero

Ans. *(d)*

In simple harmonic motion, the displacement equation is, $x=a\sin\omega t$

where, a is the amplitude of the motion.

Velocity, $v=\frac{dx}{dt}=a\omega\cos\omega t$

$$v=a\omega\sqrt{1-\sin^2\omega t}$$

$$v=\omega\sqrt{a^2-x^2} \qquad \ldots(i)$$

Acceleration, $\alpha=\frac{dv}{dt}=\frac{d}{dt}(a\omega\cos\omega t)$

$$\alpha=-a\omega^2\sin\omega t$$

$$\alpha=-\omega^2 x \qquad \ldots(ii)$$

When $x=0, v=a\omega=v_{max}$

$$\alpha=0=\alpha_{min}$$

When $x=a, v=0=v_{min}$

$$\alpha=-\omega^2 a=\alpha_{max}$$

Hence, it is clear that when v is maximum, then α is minimum (i.e. zero) or *vice-versa*.

22 The potential energy of a simple harmonic oscillator when the particle is half way to its end point is **[CBSE AIPMT 2003]**

(a) $\frac{1}{4}E$ (b) $\frac{1}{2}E$

(c) $\frac{2}{3}E$ (d) $\frac{1}{8}E$

Ans. *(a)*

Potential energy of a simple harmonic oscillator

$$U=\frac{1}{2}m\omega^2x^2$$

Kinetic energy of a simple harmonic oscillator

$$K=\frac{1}{2}m\omega^2(a^2-x^2)$$

Here, x = Displacement from mean position

a = Maximum displacement (or amplitude) from mean position

Total energy is

$$E=U+K$$

$$=\frac{1}{2}m\omega^2x^2+\frac{1}{2}m\omega^2(a^2-x^2)$$

$$=\frac{1}{2}m\omega^2a^2$$

When the particle is half way to its end point i.e. at half of its amplitude, then

$$x=\frac{a}{2}$$

Hence, potential energy

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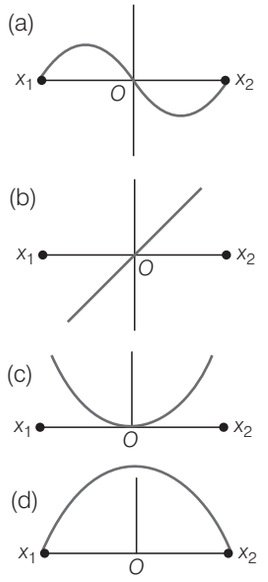
$$U = \frac{1}{2} m\omega^2 \left(\frac{a}{2}\right)^2 = \frac{1}{4}\left(\frac{1}{2} m\omega^2 a^2\right)$$

$$\Rightarrow \quad U = \frac{E}{4}$$

(where, E is the total energy)

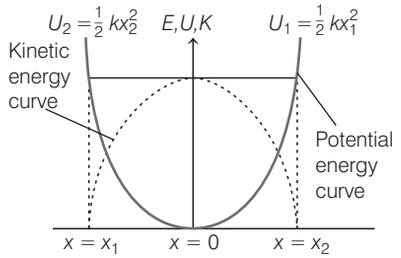
23 A particle of mass m oscillates with simple harmonic motion between points x_1 and x_2, the equilibrium position being O. Its potential energy is plotted. It will be as given below in the graph **[CBSE AIPMT 2003]**



Ans. *(c)*

Potential energy is given by $U = \frac{1}{2} kx^2$

The corresponding graph is shown in figure.



At equilibrium position ($x = 0$), potential energy is minimum. At extreme positions x_1 and x_2, its potential energies are

$$U_1 = \frac{1}{2} kx_1^2$$

and $$U_2 = \frac{1}{2} kx_2^2$$

In the above graph, the dotted line (curve) is shown for kinetic energy. This graph shows that kinetic energy is maximum at mean position and zero at extreme positions x_1 and x_2.

24 The displacement of particle between maximum potential energy position and maximum kinetic energy position in simple harmonic motion is **[CBSE AIPMT 2002]**

(a) $\pm\frac{a}{2}$ (b) $\pm a$

(c) $\pm 2a$ (d) ± 1

Ans. *(b)*

Expression of kinetic energy is

$$K = \frac{1}{2} k(a^2 - x^2) \qquad ...(i)$$

Expression of potential energy is

$$U = \frac{1}{2} kx^2 \qquad ...(ii)$$

where, $k = m\omega^2$

We observe that at mean position ($x = 0$), kinetic energy is maximum $\left(\frac{1}{2} ka^2\right)$ and potential energy is minimum (zero). Also at extreme positions ($x = \pm a$), kinetic energy is zero and potential energy is maximum $\left(\frac{1}{2} ka^2\right)$. Thus, displacement between positions of maximum potential energy and maximum kinetic energy is $\pm a$.

NOTE

Kinetic energy is zero at extreme positions but potential energy at mean position need not be zero. It is minimum at mean position.

25 In SHM restoring force is $F = -kx$, where k is force constant, x is displacement and a is amplitude of motion, then total energy depends upon **[CBSE AIPMT 2001]**

(a) k, a and m (b) k, x, m

(c) k, a (d) k, x

Ans. *(c)*

In SHM, the total energy

= potential energy + kinetic energy

or $$E = U + K$$

$$= \frac{1}{2} m\omega^2 x^2 + \frac{1}{2} m\omega^2 (a^2 - x^2)$$

$$= \frac{1}{2} m\omega^2 a^2 = \frac{1}{2} ka^2$$

where, $k =$ force constant $= m\omega^2$

Thus, total energy depends on k *and* a.

26 Two simple harmonic motions given by, $x = a\sin(\omega t + \delta)$ and $y = a\sin\left(\omega t + \delta + \frac{\pi}{2}\right)$ act on a particle simultaneously, then the motion of particle will be **[CBSE AIPMT 2000]**

(a) circular anti-clockwise

(b) circular clockwise

(c) elliptical anti-clockwise

(d) elliptical clockwise

Ans. *(b)*

Two simple harmonic motions can be written as

$$x = a\sin(\omega t + \delta) \qquad ...(i)$$

and $$y = a\sin\left(\omega t + \delta + \frac{\pi}{2}\right)$$

or $$y = a\cos(\omega t + \delta) \qquad ...(ii)$$

Squaring and adding Eqs. (i) and (ii), we obtain

$$x^2 + y^2 = a^2\,[\sin^2(\omega t + \delta) + \cos^2(\omega t + \delta)]$$

or $$x^2 + y^2 = a^2 \quad (\because \sin^2\theta + \cos^2\theta = 1)$$

This is the equation of a circle.

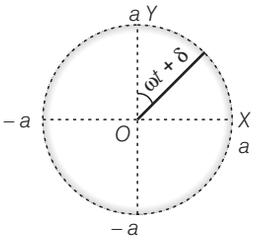
At $(\omega t + \delta) = 0$; $x = 0, y = a$

At $(\omega t + \delta) = \frac{\pi}{2}$; $x = a, y = 0$

At $(\omega t + \delta) = \pi$; $x = 0, y = -a$

At $(\omega t + \delta) = \frac{3\pi}{2}$; $x = -a, y = 0$

At $(\omega t + \delta) = 2\pi$; $x = 0, y = a$



Thus, it is obvious that motion of particle is traversed in clockwise direction.

27 Two simple harmonic motions with the same frequency act on a particle at right angles i.e. along X-axis and Y-axis. If the two amplitudes are equal and the phase difference is $\pi/2$, the resultant motion will be **[CBSE AIPMT 1997]**

(a) a circle

(b) an ellipse with the major axis along Y-axis

(c) an ellipse with the major axis along X-axis

(d) a straight line inclined at 45° to the X-axis

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Ans. *(a)*

The two simple harmonic motions can be written as

$$x = a\sin\omega t \quad ...(i)$$

and $$y = a\sin\left(\omega t + \frac{\pi}{2}\right)$$

$$y = a\cos\omega t \quad ...(ii)$$

On squaring and adding Eqs. (i) and (ii), we obtain

$$x^2 + y^2 = a^2(\sin^2\omega t + \cos^2\omega t)$$

or $x^2 + y^2 = a^2$

This is the equation of a circular motion with radius a.

NOTE

Simple harmonic motion is of two types.
1. Linear simple harmonic motion
2. Angular simple harmonic motion

28 A particle starts simple harmonic motion from the mean position. Its amplitude is a and time period is T. What is its displacement when its speed is half of its maximum speed ? **[CBSE AIPMT 1996]**

(a) $\frac{\sqrt{2}}{3}a$ (b) $\frac{\sqrt{3}}{2}a$

(c) $\frac{2}{\sqrt{3}}a$ (d) $\frac{a}{\sqrt{2}}$

Ans. *(b)*

Velocity of the particle executing SHM at any instant is defined as the time rate of change of its displacement at that instant.

Let the displacement of the particle at an instant t is given by

$$x = a\sin\omega t$$

$$\therefore \text{Velocity } v = \frac{dx}{dt} = \frac{d(a\sin\omega t)}{dt}$$

$$= a\omega\cos\omega t = a\omega\sqrt{(1-\sin^2\omega t)}$$

$$= a\omega\sqrt{\left(1-\frac{x^2}{a^2}\right)} = \omega\sqrt{(a^2-x^2)}$$

At mean position, $x = 0$

$$\therefore \quad v_{max} = \omega a$$

According to problem, $v = \frac{v_{max}}{2} = \frac{a\omega}{2}$

But $v = \omega\sqrt{a^2 - x^2}$

$$\therefore \quad \frac{a\omega}{2} = \omega\sqrt{a^2 - x^2} \quad \text{or} \quad x = \frac{\sqrt{3}}{2}a$$

29 In a simple harmonic motion, when the displacement is one-half the amplitude, what fraction of the total energy is kinetic? **[CBSE AIPMT 1996]**

(a) Zero (b) $\frac{1}{4}$

(c) $\frac{1}{2}$ (d) $\frac{3}{4}$

Ans. *(d)*

Total energy of the particle executing SHM at instant t is given by

$$E = \frac{1}{2}m\omega^2a^2 \quad ...(i)$$

and kinetic energy of the particle at instant t is given by

$$E_K = \frac{1}{2}m\omega^2(a^2 - x^2) \quad ...(ii)$$

when $$x = \frac{a}{2},\ E_K = \frac{1}{2}m\omega^2\left(a^2 - \frac{a^2}{4}\right)$$

$$= \frac{1}{2}m\omega^2 \times \frac{3}{4}a^2$$

or $$E_K = \frac{1}{2}\times\frac{3}{4}m\omega^2a^2 \quad ...(iii)$$

From Eqs. (i) and (iii)

$$\frac{E_K}{E} = \frac{3}{4} \Rightarrow E_K = \frac{3}{4}E$$

30 A body executes SHM with an amplitude a. At what displacement from the mean position, the potential energy of the body is one-fourth of its total energy ? **[CBSE AIPMT 1995]**

(a) $\frac{a}{4}$

(b) $\frac{a}{2}$

(c) $\frac{3a}{4}$

(d) Some other fraction of a

Ans. *(b)*

Potential energy of the body executing SHM is given by

$$U = \frac{1}{2}m\omega^2x^2$$

where symbols have their usual meaning.

Total energy of the body executing SHM is

$$E = \frac{1}{2}m\omega^2a^2$$

According to problem,

$$U = \frac{1}{4}E$$

$$\therefore \quad \frac{1}{2}m\omega^2x^2 = \frac{1}{4}\times\frac{1}{2}m\omega^2a^2$$

or $$x^2 = \frac{a^2}{4} \quad \text{or} \quad x = \frac{a}{2}$$

31 Which one of the following is a simple harmonic motion ? **[CBSE AIPMT 1994]**

(a) Ball bouncing between two rigid vertical walls
(b) Particle moving in a circle with uniform speed
(c) Wave moving through a string fixed at both ends
(d) Earth spinning about its own axis

Ans. *(c)*

Problem Solving Strategy To calculate the time period of combined oscillation, calculate the beat produced from the given frequencies.

In transverse wave motion individual particles of the medium execute simple harmonic motion about their mean position in a direction perpendicular to the direction of propagation of wave motion. Wave moving through a string fixed at both ends executes SHM.

32 A wave has SHM (simple harmonic motion) whose period is 4s while another wave which also possesses SHM has its period 3 s. If both are combined, then the resultant wave will have the period equal to **[CBSE AIPMT 1993]**

(a) 4 s (b) 5 s
(c) 12 s (d) 3 s

Ans. *(c)*

Problem Solving Strategy To calculate the time period of combined oscillation, calculate the beat produced from the given frequencies.

When both waves are combined, then beats are produced. Frequency of beats will be $= \nu_1 - \nu_2$

$$= \frac{1}{T_1} - \frac{1}{T_2} = \frac{1}{3} - \frac{1}{4} = \frac{1}{12}$$

Hence, time period = 12 s

33 A simple harmonic oscillator has an amplitude a and time period T. The time required by it to travel from $x = a$ to $x = \frac{a}{2}$ is **[CBSE AIPMT 1992]**

(a) $\frac{T}{6}$ (b) $\frac{T}{4}$

(c) $\frac{T}{3}$ (d) $\frac{T}{2}$

Ans. *(a)*

Equation of SHM is

$$x = a\sin\omega t \quad \text{or} \quad x = a\sin\left(\frac{2\pi}{T}\right)t$$

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when $x = a$, then

$$a = a\sin\left(\frac{2\pi}{T}\right)t$$

or $\sin\left(\frac{2\pi}{T}\right)t = 1$

or $\sin\left(\frac{2\pi}{T}\right)t = \sin\frac{\pi}{2} \Rightarrow t = \frac{T}{4}$

when $x = \frac{a}{2}$, then

$$\frac{a}{2} = a\sin\left(\frac{2\pi}{T}\cdot t\right)$$

or $\sin\left(\frac{2\pi}{T}t\right) = \sin\frac{\pi}{6}$ or $t = \frac{T}{12}$

Hence, time taken to travel from

$$x = a \text{ to } x = \frac{a}{2} = \frac{T}{4} - \frac{T}{12} = \frac{T}{6}$$

34 A body is executing SHM. When the displacements from the mean position is 4 cm and 5 cm, the corresponding velocities of the body is 10 cm/s and 8 cm/s. Then, the time period of the body is **[CBSE AIPMT 1991]**

(a) 2π sec (b) $\frac{\pi}{2}$ sec

(c) π sec (d) $\frac{3\pi}{2}$ sec

Ans. *(c)*

Velocity of the particle executing SHM at any instant is defined as the time rate of change of its displacement at that instant. It is given by

$$v = \omega\sqrt{(a^2 - x^2)}$$

where, x is displacement of the particle. is acceleration and ω is angular frequency.

Case I $10 = \omega\sqrt{a^2 - 16}$ ...(i)

Case II $8 = \omega\sqrt{a^2 - 25}$ ...(ii)

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{5}{4} = \frac{\sqrt{a^2 - 16}}{\sqrt{a^2 - 25}} \text{ or } \frac{25}{16} = \frac{a^2 - 16}{a^2 - 25}$$

or $16a^2 - 256 = 25a^2 - 625$

or $a^2 = \frac{369}{9}$

Putting value of a^2 in Eq. (i), we get

$$10 = \omega\sqrt{\left(\frac{369}{9} - 16\right)}$$

or $\omega = \frac{10 \times 3}{15} = 2$ rad/s

$\therefore$ Time period $T = \frac{2\pi}{\omega} = \frac{2\pi}{2} = \pi$ sec

35 The angular velocity and the amplitude of a simple pendulum is ω and a respectively. At a displacement x from the mean position, if its kinetic energy is T and potential energy is U, then the ratio of T to U is **[CBSE AIPMT 1991]**

(a) $\left(\frac{a^2 - x^2\omega^2}{x^2\omega^2}\right)$ (b) $\frac{x^2\omega^2}{(a^2 - x^2\omega^2)}$

(c) $\frac{(a^2 - x^2)}{x^2}$ (d) $\frac{x^2}{(a^2 - x^2)}$

Ans. *(c)*

Consider a particle of mass m, executing linear SHM with amplitude a and constant angular frequency ω. Suppose t second after starting from the mean position, the displacement of the particle is x, which is given by

$$x = a\sin\omega t$$

So, potential energy of particle is

$$U = \frac{1}{2}m\omega^2 x^2 \quad ...(i)$$

and kinetic energy of particle is

$$T = \frac{1}{2}m\omega^2(a^2 - x^2) \quad ...(ii)$$

From Eqs. (i) and (ii) $\frac{T}{U} = \frac{a^2 - x^2}{x^2}$

36 A particle moving along the X-axis executes simple harmonic motion, then the force acting on it is given by **[CBSE AIPMT 1988]**

(a) $-AKx$ (b) $A\cos Kx$

(c) $A\exp(-Kx)$ (d) AKx

where, A and K are positive constants.

Ans. *(a)*

If a particle executing simple harmonic motion, has a displacement x from its equilibrium position, at an instant the magnitude of the restoring force F acting on the particle at that instant is given by

$$F = -kx$$

where, k is known as force constant.

Hence, in given options, option (a) is correct. Here, $k = AK$

TOPIC 2
Some Systems Exceuting SHM

37 A spring is stretched by 5 cm by a force 10 N. The time period of the oscillations when a mass of 2 kg is suspended by it is **[NEET 2021]**

(a) 0.0628 s (b) 6.28 s

(c) 3.14 s (d) 0.628 s

Ans. *(d)*

Given, the mass of suspended, $m = 2$ kg

The spring is stretched, $x = 5$ cm $= 0.05$ m

The constant force applied on the spring, $F = 10$ N

As we know that, spring force,

$F = kx \Rightarrow 10\text{ N} = k(0.05\text{ m})$

$\Rightarrow k = 200$ N/m

Now, time period of the oscillation,

$$T = 2\pi\sqrt{\frac{m}{k}} \Rightarrow T = 2\pi\sqrt{\frac{2}{200}}$$

Time period, $T = 0.628$ s

38 A mass falls from a height 'h' and its time of fall 't' is recorded in terms of time period T of a simple pendulum. On the surface of earth it is found that $t = 2$ T. The entire set up is taken on the surface of another planet whose mass is half of earth and radius the same. Same experiment is repeated and corresponding times noted as t' and T'. **[NEET (Odisha) 2019]**

(a) $t' = \sqrt{2}\,T'$ (b) $t' > 2T'$

(c) $t' < 2T'$ (d) $t' = 2T'$

Ans. *(d)*

The distance covered by the mass falling from height 'h' during its time of fall 't' is given by

$$s = h = ut + \frac{1}{2}gt^2$$

As, $u = 0 \Rightarrow h = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2h}{g}}$ ...(i)

The time period of simple pendulum is

$$T = 2\pi\sqrt{\frac{l}{g}} \quad ...(ii)$$

where, l is the length of the pendulum. From Eq. (i) and (ii), since 'h' and 'l' are constant so, we can conclude that,

$$t \propto \frac{1}{\sqrt{g}} \text{ and } T \propto \frac{1}{\sqrt{g}} \therefore \frac{t}{T} = 1$$

Thus, the ratio of time of fall and time period of pendulum is independent of value of gravity (g) or any other parameter like mass and radius of the planet. Thus, the relation between t' and T' on another planet irrespective of its mass or radius will remains same as it was on earth i.e.

$$t' = 2T'$$

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39 A pendulum is hung from the roof of a sufficiently high building and is moving freely to and fro like a simple harmonic oscillator. The acceleration of the bob of the pendulum is 20 m/s^2 at a distance of 5 m from the mean position. The time period of oscillation is **[NEET 2018]**

(a) 2 s (b) π s (c) 2π s (d) 1 s

Ans. *(b)*

The acceleration of particle/body executing SHM at any instant (at position x) is given as

$$a = -\omega^2 x$$

where, ω is the angular frequency of the body.

$$\Rightarrow \quad |a| = \omega^2 x \qquad ...(i)$$

Here, $x = 5\text{m}, |a| = 20\ \text{ms}^{-2}$

Substituting the given values in Eq. (i), we get

$$20 = \omega^2 \times 5$$

$$\Rightarrow \quad \omega^2 = \frac{20}{5} = 4$$

or $\omega = 2\ \text{rad s}^{-1}$

As, we know that

Time period, $T = \dfrac{2\pi}{\omega}$ ...(ii)

$\therefore$ Substituting the value of ω in Eq. (ii), we get

$$T = \frac{2\pi}{2} = \pi\ \text{s}$$

40 A spring of force constant k is cut into lengths of ratio 1 : 2 : 3. They are connected in series and the new force constant is k'. If they are connected in parallel and force constant is k'', then $1k' : k''$ is **[NEET 2017]**

(a) 1 : 6 (b) 1 : 9 (c) 1 : 11 (d) 1 : 14

Ans. *(c)*

When the spring is cut into pieces, they will have the new force constant. The spring is divided into 1 : 2 : 3 ratio.

When the pieces are connected in series, the resultant force constant

$$\frac{1}{v'} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}$$

$$\frac{1}{v'} = \frac{1}{x} + \frac{1}{2x} + \frac{1}{3x}$$

$$v' = \frac{6x}{11}$$

In parallel, the net force constant

$$K'' = x + 2x + 3x = 6x = 11K$$

The required ratio

$$\frac{K}{K''} = \frac{6x/11}{6x} = 1 : 11$$

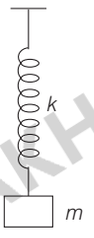
41 A body of mass m is attached to the lower end of a spring whose upper end is fixed. The spring has negligible mass. When the mass m is slightly pulled down and released, it oscillates with a time period of 3 s. When the mass m is increased by 1 kg, the time period of oscillations becomes 5 s. The value of m in kg is **[NEET 2016]**

(a) $\frac{3}{4}$ (b) $\frac{4}{3}$ (c) $\frac{16}{9}$ (d) $\frac{9}{16}$

Ans. *(d)*

As we know that

Time period, $T = 2\pi\sqrt{\dfrac{m}{k}}$



Case I

$$T_1 = 2\pi\sqrt{\frac{m}{k}} \qquad ...(i)$$

Case II When the mass m is increased by 1 kg, then $= m + 1$

From Eqs. (ii) and (i), we get

$$\frac{T_2}{T_1} = \sqrt{\frac{m+1}{m}}$$

$$\Rightarrow \quad \frac{5}{3} = \sqrt{\frac{m+1}{m}} \Rightarrow \frac{25}{9} = \frac{m+1}{m}$$

$$\Rightarrow \frac{25}{9} = 1 + \frac{1}{m} \quad \Rightarrow \frac{1}{m} = \frac{16}{9}$$

$$\therefore \quad m = \frac{9}{16}\ \text{kg}$$

42 The period of oscillation of a mass M suspended from a spring of negligible mass is T. If along with it another mass M is also suspended, the period of oscillation will now be **[CBSE AIPMT 2010]**

(a) T (b) $T/\sqrt{2}$ (c) $2T$ (d) $\sqrt{2}T$

Ans. *(d)*

Time period of spring pendulum,

$$T = 2\pi\sqrt{\frac{M}{k}}.$$

If mass is doubled then time period

$$T' = 2\pi\sqrt{\frac{2M}{k}} = \sqrt{2}T$$

43 A simple pendulum performs simple harmonic motion about $x = 0$ with an amplitude a and time period T. The speed of the pendulum at $x = \dfrac{a}{2}$ will be **[CBSE AIPMT 2009]**

(a) $\dfrac{\pi a\sqrt{3}}{2T}$ (b) $\dfrac{\pi a}{T}$ (c) $\dfrac{3\pi^2 a}{T}$ (d) $\dfrac{\pi a\sqrt{3}}{T}$

Ans. *(d)*

Concept Use the equation of motion of a body executing SHM.

i.e. $x = a\sin\omega t$

As we know, the velocity of body executing SHM is given by

$$v = \frac{dx}{dt} = a\omega\cos\omega t = a\omega\sqrt{1 - \sin^2\omega t}$$

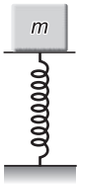
$$= \omega\sqrt{a^2 - x^2}$$

Here, $x = \dfrac{a}{2}$

$$\therefore \quad v = \omega\sqrt{a^2 - \frac{a^2}{4}} = \omega\sqrt{\frac{3a^2}{4}}$$

$$= \frac{2\pi}{T}\frac{a\sqrt{3}}{2} = \frac{\pi a\sqrt{3}}{T}$$

44 A mass of 2.0 kg is put on a flat pan attached to a vertical spring fixed on the ground as shown in the figure. The mass of the spring and the pan is negligible. When pressed slightly and released the mass executes a simple harmonic motion. The spring constant is 200 N/m. What should be the minimum amplitude of the motion, so that the mass gets detached from the pan? (Take $g = 10\ \text{m/s}^2$) **[CBSE AIPMT 2007]**



(a) 8.0 cm
(b) 10.0 cm
(c) Any value less than 12.0 cm
(d) 4.0 cm

Ans. *(b)*

Let the minimum amplitude of SHM be a. Restoring force on spring

$$F = ka$$

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Restoring force is balanced by weight mg of block. For mass to execute simple harmonic motion of amplitude a.

$\therefore \quad ka = mg \quad \text{or} \quad a = \frac{mg}{k}$

Here, $m = 2$ kg, $k = 200$ N/m,

$g = 10 \text{ m/s}^2$

$\therefore \quad a = \frac{2 \times 10}{200} = \frac{10}{100} \text{ m}$

$= \frac{10}{100} \times 100 \text{ cm} = 10 \text{ cm}$

Hence, minimum amplitude of the motion should be 10 cm, so that the mass gets detached from the pan.

45 A rectangular block of mass m and area of cross-section A floats in a liquid of density ρ. If it is given a small vertical displacement from equilibrium, it undergoes oscillation with a time period T. Then **[CBSE AIPMT 2006]**

(a) $T \propto \sqrt{\rho}$ (b) $T \propto \frac{1}{\sqrt{A}}$

(c) $T \propto \frac{1}{\rho}$ (d) $T \propto \frac{1}{\sqrt{m}}$

Ans. *(b)*

Let block be displaced through x m, then weight of displaced water or upthrust, (upwards) is given by Archimedes principle

$F_b = -Ax\rho g$

where, A is the a rea of cross-section of the block and ρ is its density. This must be equal to force ($=ma$) applied, where, m is the mass of the block and a is the acceleration.

$\therefore \quad ma = -Ax\rho g \quad \text{or} \quad a = -\frac{A\rho g}{m} x = -\omega^2 x$

This is the equation of simple harmonic motion. Time period of oscillation,

$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{A\rho g}} \Rightarrow T \propto \frac{1}{\sqrt{A}}$

46 Two springs of spring constants k_1 and k_2 are joined in series. The effective spring constant of the combination is given by **[CBSE AIPMT 2004]**

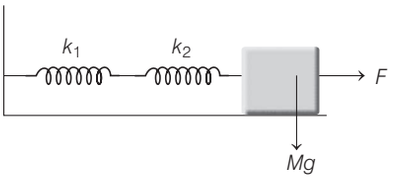
(a) $\sqrt{k_1 k_2}$ (b) $\frac{(k_1 + k_2)}{2}$

(c) $k_1 + k_2$ (d) $\frac{k_1 k_2}{(k_1 + k_2)}$

Ans. *(d)*

Let us consider two springs of spring constants k_1 and k_2 joined in series as shown in figure.

Under a force F, they will stretch by y_1 and y_2.



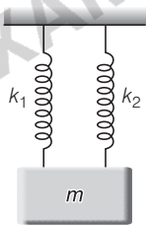
So, $y = y_1 + y_2$

or $\frac{F}{k} = \frac{F_1}{k_1} + \frac{F_2}{k_2}$

But as springs are massless, so force on them must be same i.e. $F_1 = F_2 = F$.

So, $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$ or $k = \frac{k_1 k_2}{k_1 + k_2}$

47 A mass is suspended separately by two springs of spring constants k_1 and k_2 in successive order. The time periods of oscillations in the two cases are T_1 and T_2 respectively. If the same mass be suspended by connecting the two springs in parallel, (as shown in figure) then the time period of oscillations is T. The correct relation is **[CBSE AIPMT 2002]**



(a) $T^2 = T_1^2 + T_2^2$

(b) $T^{-2} = T_1^{-2} + T_2^{-2}$

(c) $T^{-1} = T_1^{-1} + T_2^{-1}$

(d) $T = T_1 + T_2$

Ans. *(b)*

Problem Solving Strategy Calculate the effective force constant of parallel spring, then by putting the values of time period $T = 2\pi\sqrt{\frac{M}{K}}$, we get the new time period of spring.

We can write time period for a vertical spring-block system as

$T = 2\pi\sqrt{\frac{l}{g}}$

Here, l is extension in the spring when the mass m is suspended from the spring.

This can be seen as under :

$kl = mg$

(in equilibrium position)

$\Rightarrow \quad \frac{m}{k} = \frac{l}{g}$

$\therefore \quad T = 2\pi\sqrt{\frac{m}{k}}$

$\therefore \quad T_1 = 2\pi\sqrt{\frac{m}{k_1}}$

$\Rightarrow \quad k_1 = 4\pi^2 \frac{m}{T_1^2}$ ...(i)

$T_2 = 2\pi\sqrt{\frac{m}{k_2}}$

$\Rightarrow \quad k_2 = 4\pi^2 \frac{m}{T_2^2}$ ...(ii)

Since, springs are in parallel, effective force constant

$k = k_1 + k_2$

$\therefore \quad T = 2\pi\sqrt{\frac{m}{k_1 + k_2}}$

$\Rightarrow \quad k_1 + k_2 = 4\pi^2 \frac{m}{T^2}$ ...(iii)

Substituting values of k_1 and k_2 from Eqs. (i) and (ii) in Eq. (iii), we get

$4\pi^2 \frac{m}{T_1^2} + 4\pi^2 \frac{m}{T_2^2} = 4\pi^2 \frac{m}{T^2}$

$\Rightarrow \quad \frac{1}{T^2} = \frac{1}{T_1^2} + \frac{1}{T_2^2}$

or $T^{-2} = T_1^{-2} + T_2^{-2}$

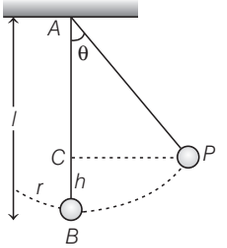
48 A pendulum is displaced to an angle θ from its equilibrium position, then it will pass through its mean position with a velocity v equal to **[CBSE AIPMT 2000]**

(a) $\sqrt{2gl}$ (b) $\sqrt{2gl \sin\theta}$

(c) $\sqrt{2gl \cos\theta}$ (d) $\sqrt{2gl(1 - \cos\theta)}$

Ans. *(d)*

If l is the length of pendulum and θ the angular amplitude, then height



$h = AB - AC$

$= l - l\cos\theta$

$= l(1 - \cos\theta)$ ...(i)

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At point P (maximum displacement position i.e. extreme position), potential energy is maximum and kinetic energy is zero. At point B (mean or equilibrium position) potential energy is minimum and kinetic energy is maximum, so from principle of conservation of energy.

$$(PE + KE) \text{ at } P = (KE + PE) \text{ at } B$$

or $$mgh + 0 = \frac{1}{2}mv^2 + 0$$

or $$v = \sqrt{2gh} \quad \ldots(ii)$$

Substituting the value of h from Eq. (i) into Eq. (ii), we get

$$v = \sqrt{2gl(1-\cos\theta)}$$

49 The time period of a simple pendulum is 2 s. If its length is increased by 4 times, then its period becomes **[CBSE AIPMT 1999]**

(a) 16 s (b) 12 s
(c) 8 s (d) 4 s

Ans. *(d)*

Time period of simple pendulum

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where, l = length of pendulum

g = acceleration due to gravity

i.e. $$T \propto \sqrt{l}$$

Hence, $$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} \quad \ldots(i)$$

Given, $l_2 = 4l_1, T_1 = 2$ s

Substituting the values in Eq. (i), we get

$$T_2 = \sqrt{\frac{4l_1}{l_1}} \times 2 = 2 \times 2 = 4 \text{ s}$$

50 A mass m is vertically suspended from a spring of negligible mass, the system oscillates with a frequency n. What will be the frequency of the system, if a mass $4m$ is suspended from the same spring ? **[CBSE AIPMT 1998]**

(a) $\frac{n}{4}$ (b) $4n$
(c) $\frac{n}{2}$ (d) $2n$

Ans. *(c)*

Time period of spring-mass system, is given by

$$T = 2\pi\sqrt{\left(\frac{\text{displacement}}{\text{acceleration}}\right)}$$

$\therefore$ Frequency, $$n = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{\text{acceleration}}{\text{displacement}}}$$

$$n = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \quad \ldots(i)$$

In case of vertical spring-mass system, in equilibrium position

$$kl = mg \Rightarrow \frac{g}{l} = \frac{k}{m}$$

where, l = extension in the spring and

m = mass of the suspended body

k = spring constant or force constant of spring.

$\therefore$ From Eq. (i), we have

$$n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \text{ or } n \propto \frac{1}{\sqrt{m}} \text{ or } \frac{n_1}{n_2} = \sqrt{\frac{m_2}{m_1}}$$

but $m_1 = m$, $m_2 = 4m$, $n_1 = n$ (given)

$\therefore$ $$\frac{n}{n_2} = \sqrt{\frac{4m}{m}} = 2 \text{ or } n_2 = \frac{n}{2}$$

Alternative

As we know that

$$T = 2\pi\sqrt{\frac{m}{k}} \quad \text{(for spring mass system)}$$

$$n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

So, for two different masses suspended with same spring.

$$n_1 = \frac{1}{2\pi}\sqrt{\frac{k}{m_1}}$$

[k is same for both the cases as spring is same]

$$n_2 = \frac{1}{2\pi}\sqrt{\frac{k}{m_2}}$$

so, $$\frac{n_1}{n_2} = \sqrt{\frac{m_2}{m_1}}$$

here, $m_2 = 4m_1$

so, $$\frac{n_1}{n_2} = \sqrt{\frac{4m_1}{m_1}} = \frac{2}{1}$$

$\Rightarrow$ $n_1 = 2n_2$

$\Rightarrow$ $$n_2 = \frac{n_1}{2} = \frac{n}{2} \quad [n_1 = n]$$

51 Two simple pendulums of length 0.5 m and 2.0 m respectively are given small linear displacement in one direction at the same time. They will again be in the same phase when the pendulum of shorter length has completed oscillations **[CBSE AIPMT 1998]**

(a) 5 (b) 1
(c) 2 (d) 3

Ans. *(c)*

For the pendulum to be again in the same phase, there should be difference of one complete oscillation.

If smaller pendulum completes n oscillations the larger pendulum will complete $(n-1)$ oscillations, so

Time period of n oscillations of first = Time period of $(n-1)$ oscillations of second

i.e. $$nT_1 = (n-1)T_2$$

or $$n2\pi\sqrt{\frac{l_1}{g}} = (n-1)2\pi\sqrt{\frac{l_2}{g}}$$

or $$n\sqrt{l_1} = (n-1)\sqrt{l_2}$$

or $$\frac{n}{n-1} = \sqrt{\frac{l_2}{l_1}} = \sqrt{\frac{2.0}{0.5}}$$

or $$\frac{n}{n-1} = 2 \quad \text{or} \quad n = 2n - 2$$

$\therefore$ $$n = 2$$

52 A hollow sphere is filled with water. It is hung by a long thread. As the water flows out of a hole at the bottom, the period of oscillation will **[CBSE AIPMT 1997]**

(a) first increase and then decrease
(b) first decrease and then increase
(c) increase continuously
(d) decrease continuously

Ans. *(a)*

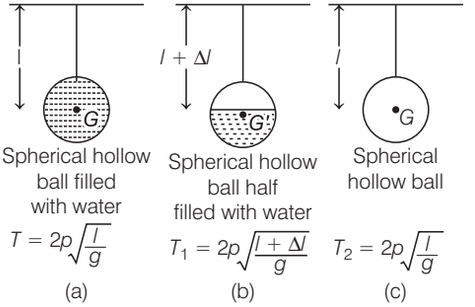
Problem Solving Strategy Compare the time period of two different oscillation.

Time period of simple pendulum

$$T = 2\pi\sqrt{\left(\frac{l}{g}\right)} \propto \sqrt{l}$$

where, l is effective length.

(i.e. distance between centre of suspension and centre of gravity of bob)



Spherical hollow ball filled with water — $T = 2p\sqrt{\frac{l}{g}}$ (a)

Spherical hollow ball half filled with water — $T_1 = 2p\sqrt{\frac{l+\Delta l}{g}}$ (b)

Spherical hollow ball — $T_2 = 2p\sqrt{\frac{l}{g}}$ (c)

Initially, centre of gravity is at the centre of sphere [Fig. (a)]. When water leaks the centre of gravity goes down until it is half-filled [Fig. (b)], then it begins to go up and finally it again

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goes at the centre [Fig. (c)]. That is effective length first increases and then decreases. As $T \propto \sqrt{l}$, so time period first increases and then decreases.

53 A linear harmonic oscillator of force constant 2×10^6 N/m and amplitude 0.01 m has a total mechanical energy of 160 J. Its **[CBSE AIPMT 1996]**

(a) maximum potential energy is 160 J
(b) maximum potential energy is 100 J
(c) maximum potential energy is zero
(d) minimum potential energy is 100 J

Ans. *(a)*

The potential energy of a particle executing SHM is given by,

$$U = \frac{1}{2} m\omega^2 x^2$$

U is maximum, when $x = a$ = amplitude of vibration i.e. the particle is passing from the extreme position and is minimum when $x = 0$, i.e. the particle is passing from the mean position

$$U_{max} = \frac{1}{2} m\omega^2 a^2 \quad ...(i)$$

Also, total energy of the particle at instant t is given by

$$E = \frac{1}{2} m\omega^2 a^2 \quad ...(ii)$$

So, when E = 160 J, then maximum potential energy of particle will also be 160 J.

Alternative

$(KE)_{max} = (PE)_{max}$
= Total Mechanical Energy
So, Total Mechanical Energy = 160 J

54 A particle is subjected to two mutually perpendicular simple harmonic motions such that its x and y coordinates are given by $x = 2\sin\omega t, y = 2\sin\left(\omega t + \frac{\pi}{4}\right)$

The path of the particle will be **[CBSE AIPMT 1994]**

(a) a straight line (b) a circle
(c) an ellipse (d) a parabola

Ans. *(c)*

Here, the phase difference between waves is $\frac{\pi}{4}$. So, the resultant path of particle will be ellipse.

55 If a simple harmonic oscillator has got a displacement of 0.02 m and acceleration equal to 2.0 m/s^2 at any time, the angular frequency of the oscillator is equal to **[CBSE AIPMT 1992]**

(a) 10 rad/s (b) 0.1 rad/s
(c) 100 rad/s (d) 1 rad/s

Ans. *(a)*

Time period of body executing SHM is given by

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{x}{a}} \quad ...(i)$$

where, x is displacement of the particle and a is acceleration of the particle.

From Eq. (i)

$$\omega = \sqrt{\frac{a}{x}} \text{ or } \omega^2 = \frac{a}{x}$$

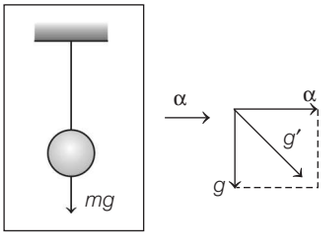
Here, $a = 2.0$ m/s^2
$x = 0.02$ m
$\therefore \quad \omega^2 = \frac{2.0}{0.02}$
or $\omega^2 = 100$
or $\omega = 10$ rad/s

56 A simple pendulum is suspended from the roof of a trolley which moves in a horizontal direction with an acceleration α, then the time period is given by $T = 2\pi\sqrt{\left(\frac{l}{g}\right)}$, where g is equal to **[CBSE AIPMT 1991]**

(a) g (b) $g - \alpha$
(c) $g + \alpha$ (d) $\sqrt{(g^2 + \alpha^2)}$

Ans. *(d)*

Problem Solving Strategy Apply vector formula to determine resultant acceleration of the both.



The bob is now under the combined action of two accelerations, g vertically downwards and α along the horizontal.

$\therefore$ Resultant acceleration

$$g' = \sqrt{g^2 + \alpha^2}$$

57 The composition of two simple harmonic motions of equal periods at right angle to each other and with a phase difference of π results in the displacement of the particle along **[CBSE AIPMT 1990]**

(a) circle (b) figure of eight
(c) straight line (d) ellipse

Ans. *(c)*

Let the SHM's be

$x = a\sin\omega t$ ...(i)

and $y = b\sin(\omega t + \pi)$

or $y = -b\sin\omega t$ ...(ii)

From Eqs. (i) and (ii)

$$\frac{x}{a} = \sin\omega t \text{ and } -\frac{y}{b} = \sin\omega t$$

$$\therefore \quad \frac{x}{a} = -\frac{y}{b} \text{ or } y = -\frac{b}{a}x$$

It is an equation of a straight line.

58 A mass m is suspended from the two coupled springs connected in series. The force constant for springs are k_1 and k_2. The time period of the suspended mass will be **[CBSE AIPMT 1990]**

(a) $T = 2\pi\sqrt{\frac{m}{k_1 - k_2}}$

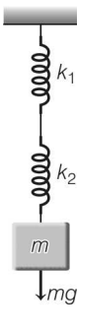
(b) $T = 2\pi\sqrt{\frac{mk_1k_2}{k_1 + k_2}}$

(c) $T = 2\pi\sqrt{\frac{m}{k_1 + k_2}}$

(d) $T = 2\pi\sqrt{\frac{m(k_1 + k_2)}{k_1k_2}}$

Ans. *(d)*

Problem Solving Strategy Derive an expression from the given values which must be simillar to $a = -\omega^2 x$. Then calculate time period from the values in place of ω.



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The situation is shown in figure. Consider two springs of spring constants k_1 and k_2. Here, the body of weight mg is suspended at the free end of the two springs in series combination. When the body is pulled downwards through a little distance y, the two springs suffer different extensions say y_1 and y_2. But the restoring force is same in each spring.

$\therefore \quad F = -k_1 y_1$

and $\quad F = -k_2 y_2$

or $\quad y_1 = -\frac{F}{k_1}$

and $\quad y_2 = -\frac{F}{k_2}$

$\therefore$ Total extension, $y = y_1 + y_2$

$$= -\frac{F}{k_1} - \frac{F}{k_2}$$

$$= -F\left(\frac{k_1 + k_2}{k_1 k_2}\right)$$

or $$F = -\left(\frac{k_1 k_2}{k_1 + k_2}\right) y$$

If k is the spring constant of series combination of springs then

$$F = -ky$$

$\therefore \quad k = \frac{k_1 k_2}{k_1 + k_2}$

If the body is left free after pulling down, it will execute SHM of period

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$= 2\pi\sqrt{\frac{m(k_1 + k_2)}{k_1 k_2}}$$

TOPIC 3
Forced, Damped Oscillations and Resonance

59 The damping force on an oscillator is directly proportional to the velocity. The units of the constant of proportionality are

[CBSE AIPMT 2012]

(a) kg ms^{-1} (b) kg ms^{-2}
(c) kg s^{-1} (d) kg s

Ans. *(c)*

Given,

Damping force $\propto$ velocity

$$F \propto v$$

$$F = kv \quad \Rightarrow \quad k = \frac{F}{v}$$

$$\text{Unit of } k = \frac{\text{unit of } F}{\text{unit of } v} = \frac{\text{kg - ms}^{-2}}{\text{ms}^{-1}} = \text{kg s}^{-1}$$

60 When a damped harmonic oscillator completes 100 oscillations, its amplitude is reduced to $\frac{1}{3}$ of its initial value.

What will be its amplitude when it completes 200 oscillations ?

[CBSE AIPMT 2002]

(a) $\frac{1}{5}$ (b) $\frac{2}{3}$ (c) $\frac{1}{6}$ (d) $\frac{1}{9}$

Ans. *(d)*

In case of damped vibration, amplitude at any instant t is given by

$$a = a_0 e^{-bt}$$

where, a_0 = initial amplitude

b = damping constant

Case I $t = 100T$ and $a = \frac{a_0}{3}$

$\therefore \quad \frac{a_0}{3} = a_0 e^{-b\,(100\,T)}$

$\Rightarrow \quad e^{-100\,bT} = \frac{1}{3}$

Case II $t = 200T$

$$a = a_0 e^{-bt} = a_0 e^{-b\,(200\,T)}$$

$$= a_0 (e^{-100\,bT})^2 = a_0 \times \left(\frac{1}{3}\right)^2 = \frac{a_0}{9}$$

Thus, after 200 oscillations, amplitude will become $\frac{1}{9}$ times.

61 A particle, with restoring force proportional to displacement and resisting force proportional to velocity is subjected to a force $F \sin\omega t$. If the amplitude of the particle is maximum for $\omega = \omega_1$, and the energy of the particle is maximum for $\omega = \omega_2$, then

[CBSE AIPMT 1989]

(a) $\omega_1 = \omega_0$ and $\omega_2 \neq \omega_0$
(b) $\omega_1 = \omega_0$ and $\omega_2 = \omega_0$
(c) $\omega_1 \neq \omega_0$ and $\omega_2 = \omega_0$
(d) $\omega_1 \neq \omega_0$ and $\omega_2 \neq \omega_0$

Ans. *(c)*

In harmonic oscillator, the energy is maximum at $\omega_2 = \omega_0$ and amplitude is maximum at frequency $\omega_1 < \omega_0$ in the presence of damping, so $\omega_1 \neq \omega_0$ and $\omega_2 = \omega_0$.

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14
Waves

TOPIC 1
Basics of Waves

01 A uniform rope of length L and mass m_1 hangs vertically from a rigid support. A block of mass m_2 is attached to the free end of the rope. A transverse pulse of wavelength λ_1 is produced at the lower end of the rope. The wavelength of the pulse when it reaches the top of the rope is λ_2. The ratio λ_2/λ_1 is **[NEET 2016]**

(a) $\sqrt{\frac{m_1+m_2}{m_2}}$ (b) $\sqrt{\frac{m_2}{m_1}}$

(c) $\sqrt{\frac{m_1+m_2}{m_1}}$ (d) $\sqrt{\frac{m_1}{m_2}}$

Ans. *(a)*

According to question, we have

Wavelength of transphase pulse

$$\lambda = \frac{v}{f} \quad ...(i)$$

(v = velocity of the wave; f = frequency of the wave)

As we know $v = \sqrt{\frac{T}{\mu}}$ ...(ii)

(T = tension in the spring; μ = mass per unit length of the rope)

From Eqs. (i) and (ii), we get

$$\lambda = \frac{1}{f}\sqrt{\frac{T}{\mu}}$$

$$\Rightarrow \quad \lambda \propto \sqrt{T}$$

So, for two different case, we get

$$\frac{\lambda_2}{\lambda_1} = \sqrt{\frac{T_2}{T_1}}$$

$$= \sqrt{\frac{m_1+m_2}{m_2}}$$

02 A wave travelling in the positive x-direction having displacement along y-direction as 1 m, wavelength 2π m and frequency of $\frac{1}{\pi}$ Hz is represented by **[NEET 2013]**

(a) $y = \sin(x - 2t)$

(b) $y = \sin(2\pi x - 2\pi t)$

(c) $y = \sin(10\pi x - 20\pi t)$

(d) $y = \sin(2\pi x + 2\pi t)$

Ans. *(a)*

Given, $a = 1$ m

As $y = a\sin(kx - \omega t)$

$$= \sin\left(\frac{2\pi}{2\pi} - 2\pi \times \frac{1}{\pi}t\right) = \sin(x - 2t)$$

03 Two waves are represented by the equations $y_1 = a\sin(\omega t + kx + 0.57)$ m and $y_2 = a\cos(\omega t + kx)$ m, where x is in metre and t in second. The phase difference between them is **[CBSE AIPMT 2011]**

(a) 1.25 rad (b) 1.57 rad

(c) 0.57 rad (d) 1 rad

Ans. *(d)*

According to question,

$$y_1 = a\sin(\omega t + kx + 0.57)$$

and $y_2 = a\cos(\omega t + kx)$

or $y_2 = a\sin\left(\frac{\pi}{2} + \omega t + kx\right)$

As phase difference,

$$\Delta\phi = \phi_2 - \phi_1 = \frac{\pi}{2} - 0.57$$

$$= 1.57 - 0.57 = 1 \text{ rad}$$

04 Sound waves travel at 350 m/s through a warm air and at 3500 m/s through brass. The wavelength of a 700 Hz acoustic wave as it enters brass from warm air **[CBSE AIPMT 2011]**

(a) increases by a factor 20

(b) increases by a factor 10

(c) decreases by a factor 20

(d) decreases by a factor 10

Ans. *(b)*

Velocity of a wave is given by

$$v = n\lambda$$

[n = frequency of wave; λ = wavelength of wave]

So, for two different cases,

$$v_1 = n_1\lambda_1$$

$$v_2 = n_2\lambda_2$$

$$\lambda_2 = \lambda_1\frac{v_2}{v_1}$$

$$= \lambda_1 \times \frac{3500}{350} = \lambda_1 \times 10$$

[$\because n_1 = n_2$]

$$\lambda_2 = 10\,\lambda_1$$

05 A transverse wave is represented by $y = A\sin(\omega t - kx)$. For what value of the wavelength is the wave velocity equal to the maximum particle velocity? **[CBSE AIPMT 2010]**

(a) $\pi A/2$ (b) πA

(c) $2\pi A$ (d) A

Ans. *(c)*

Given, $y = A\sin(\omega t - kx)$

As we know that wave velocity is given by

$$v_w = \frac{\lambda}{T} = \frac{\omega\lambda}{2\pi} \quad ...(i)$$

$$\left[T = \frac{2\pi}{\omega}\right]$$

and maximum particle velocity is given by

$$v_p = A\omega \quad ...(ii)$$

[A = amplitude; ω = angular frequency]

So, as Eq. (i) is equal to Eq. (ii),

$$A\omega = \frac{\omega\lambda}{2\pi}, \quad \lambda = 2\pi A$$

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06 A wave in a string has an amplitude of 2cm. The wave travels in the positive direction of x-axis with a speed of 128 ms^{-1} and it is noted that 5 complete waves fit in 4 m length of the string. The equation describing the wave is **[CBSE AIPMT 2009]**

(a) $y = (0.02)\text{m} \sin(7.85x + 1005\ t)$
(b) $y = (0.02)\text{ m} \sin(15.7x - 2010\ t)$
(c) $y = (0.02)\text{m} \sin(15.7x + 2010\ t)$
(d) $y = (0.02)\text{ m} \sin(7.85x - 1005\ t)$

Ans. *(d)*

Given, amplitude of wave, $A = 2$ cm

direction = +ve x direction

Velocity of wave

$$v = 128\ ms^{-1}$$

and length of string, $5\lambda = 4$

We know that,

$$k = \frac{2\pi}{\lambda} = \frac{2\pi \times 5}{4} = 7.85$$

and $$v = \frac{\omega}{k} = 128\ ms^{-1}$$

[ω = Angular frequency]

$$\Rightarrow \quad \omega = v \times k = 128 \times 7.85 = 1005$$

As, the wave travelling towards + x-axis is given by

$$y = A \sin(kx - \omega t)$$

So, $y = 2 \sin(7.85\, x - 1005\, t)$

$y = (0.02)\text{ m} \sin(7.85\, x - 1005\, t)$

07 The wave described by $y = 0.25 \sin(10\pi x - 2\pi t)$, where, x and y are in metre and t in second, is a wave travelling along the **[CBSE AIPMT 2008]**

(a) negative x-direction with frequency 1 Hz
(b) positive x-direction with frequency π Hz and wavelength $\lambda = 0.2$ m
(c) positive x-direction with frequency 1 Hz and wavelength $\lambda = 0.2$ m
(d) negative x-direction with amplitude 0.25 m and wavelength $\lambda = 0.2$ m

Ans. *(c)*

$y = 0.25 \sin(10\pi x - 2\pi t)$

Compare the above equation with

$$y = A \sin(kx - \omega t)$$

As ωt and kx have opposite sign, wave travels along positive x.

As, $\quad 2\pi t = \omega t$

$\Rightarrow \quad \omega = 2\pi = 2\pi\nu$

$\Rightarrow \quad \nu = 1$ Hz

Also, $\quad kx = 10\pi x$

$$k = 10\pi = \frac{2\pi}{\lambda}$$

$$\lambda = \frac{2\pi}{10\pi} = 0.2$$

Hence, option (c) is correct.

08 Which one of the following statements is true ? **[CBSE AIPMT 2006]**

(a) Both light and sound waves in air are transverse
(b) he sound waves in air are longitudinal while the light waves are transverse
(c) Both light and sound waves in air are longitudinal
(d) Both light and sound waves can travel in vacuum

Ans. *(b)*

In a longitudinal wave, the particles of the medium oscillate about their mean or equilibrium position along the direction of propagation of the wave itself. Sound waves are longitudinal in nature. In transverse wave, the particles of the medium oscillate about their mean or equilibrium position at right angles to the direction of propagation of wave itself. Light waves being electromagnetic are transverse waves.

09 The time of reverberation of a room A is 1s. What will be the time (in second) of reverberation of a room, having all the dimensions double of those of room A? **[CBSE AIPMT 2006]**

(a) 2 (b) 4
(c) $\frac{1}{2}$ (d) 1

Ans. *(a)*

Sabine's formula for reverberation time is

$$T = \frac{0.16\, V}{\Sigma as}$$

$$T \propto \frac{V}{s}$$

where, V is volume of hall in m^3.

$\Sigma as = a_1 s_1 + a_2 s_2 + \ldots$

= total absorption of the hall (room)

Here, $s_1, s_2, s_3 \ldots$ are surface areas of the absorbers and $a_1, a_2, a_3 \ldots$ are their respective absorption coefficients.

So, for two different cases of reverberation.

$$\therefore \quad \frac{T'}{T} = \frac{V'}{s'} \times \frac{s}{V}$$

$$= \frac{(2)^3}{(2)^2} = \frac{8}{4} = 2$$

Hence, $\quad T' = 2T = 2 \times 1 = 2\text{s}$

10 A transverse wave propagating along x-axis is represented by

$$y(x,t) = 8 \sin\left(0.5\,\pi x - 4\pi t - \frac{\pi}{4}\right),$$

where, x is in metre and t is in second. The speed of the wave is **[CBSE AIPMT 2006]**

(a) 4π m/s (b) $0.5\,\pi$ m/s
(c) $\frac{\pi}{4}$ m/s (d) 8 m/s

Ans. *(d)*

The given equation is

$$y(x,t) = 8.0 \sin\left(0.5\,\pi x - 4\pi t - \frac{\pi}{4}\right) \quad \ldots(i)$$

Compare it with the standard wave equation

$$y = a \sin(kx - \omega t + \phi) \quad \ldots(ii)$$

where a is amplitude, k the propagation constant and ω the angular frequency, comparing the Eqs. (i) and (ii), we have

$$k = 0.5\pi, \omega = 4\pi$$

$\therefore$ Speed of transverse wave,

$$v = \frac{\omega}{k} = \frac{4\pi}{0.5\,\pi} = 8\,\text{m/s}$$

11 A point source emits sound equally in all directions in a non-absorbing medium. Two points P and Q are at distance of 2m and 3m respectively from the source. The ratio of the intensities of the waves at P and Q is **[CBSE AIPMT 2005]**

(a) 9 : 4 (b) 2 : 3 (c) 3 : 2 (d) 4 : 9

Ans. *(a)*

Intensity of sound, $I = \frac{p}{4\pi r^2}$

[p = pressure of sound waves
r = distance between source and the point]

or $$I \propto \frac{1}{r^2}$$

or $$\frac{I_1}{I_2} = \left(\frac{r_2}{r_1}\right)^2$$

Here, $\quad r_1 = 2\text{m}, r_2 = 3\text{m}$

Substituting the values, we have

$$\frac{I_1}{I_2} = \left(\frac{3}{2}\right)^2 = \frac{9}{4}$$

12 The phase difference between two waves, represented by

$$y_1 = 10^{-6} \sin\left\{100t + \left(\frac{x}{50}\right) + 0.5\right\}\text{m}$$

$$y_2 = 10^{-6} \cos\left\{100t + \left(\frac{x}{50}\right)\right\}\text{m},$$

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where, x is expressed in metre and t is expressed in second, is approximately **[CBSE AIPMT 2004]**

(a) 1.07 rad (b) 2.07 rad
(c) 0.5 rad (d) 1.5 rad

Ans. *(a)*

The given waves are

$$y_1 = 10^{-6}\sin\left[100t + \left(\frac{x}{50}\right) + 0.5\right]\text{m} \quad ...(i)$$

and $$y_2 = 10^{-6}\cos\left[100t + \left(\frac{x}{50}\right)\right]\text{m} \quad ...(ii)$$

Eq. (ii) can be written as

$$\Rightarrow \quad y_2 = 10^{-6}\sin\left[100t + \left(\frac{x}{50}\right) + \frac{\pi}{2}\right]\text{m}$$

$$\left[\because \sin\left(\frac{\pi}{2} + \theta\right) = \cos\theta\right]$$

Hence, the phase difference between the waves is

$$\Delta\phi = \left(\frac{\pi}{2} - 0.5\right)\text{rad}$$
$$= \left(\frac{3.14}{2} - 0.5\right)\text{rad}$$
$$= (1.57 - 0.5)\text{ rad}$$
$$= (1.07)\text{ rad}$$

NOTE

The given waves are sine and cosine functions, so they are plane progressive harmonic waves.

13 A wave of amplitude $a = 0.2\,\text{m}$, velocity $v = 360\,\text{m/s}$ and wavelength 60 m is travelling along positive x-axis, then the correct expression for the wave is **[CBSE AIPMT 2002]**

(a) $y = 0.2\sin 2\pi\left(6t + \frac{x}{60}\right)$

(b) $y = 0.2\sin\pi\left(6t + \frac{x}{60}\right)$

(c) $y = 0.2\sin 2\pi\left(6t - \frac{x}{60}\right)$

(d) $y = 0.2\sin\pi\left(6t - \frac{x}{60}\right)$

Ans. *(c)*

The general expression of travelling wave can be written as

$$y = a\sin(\omega t \pm kx) \quad ...(i)$$

For travelling wave along positive x-axis we should use minus (−) sign only.

$$\therefore \quad y = a\sin(\omega t - kx)$$

but $$\omega = \frac{2\pi v}{\lambda} \text{ and } k = \frac{2\pi}{\lambda}$$

So, $$y = a\sin\frac{2\pi}{\lambda}(vt - x) \quad ...(ii)$$

Given, $a = 0.2$ m, $v = 360$ m/s, $\lambda = 60$ m, Substituting in Eq. (ii), we have

$$y = 0.2\sin\frac{2\pi}{60}(360\,t - x)$$

or $$y = 0.2\sin 2\pi\left(6t - \frac{x}{60}\right)$$

14 The equation of a wave is given by $y = a\sin\left(100t - \frac{x}{10}\right)$, where x and y are in metre and t in second, then velocity of wave is **[CBSE AIPMT 2001]**

(a) 0.1 m/s (b) 10 m/s
(c) 100 m/s (d) 1000 m/s

Ans. *(d)*

The given wave equation is

$$y = a\sin\left(100t - \frac{x}{10}\right)$$

Compare it with the standard wave equation, we obtain

$$\omega = 100,\ k = \frac{1}{10}$$

Velocity of the wave,

$$v = \frac{\omega}{k} = \frac{100}{1/10}$$
$$= 100 \times 10 = 1000\text{ m/s}$$

15 A wave enters to water from air. In air frequency, wavelength, intensity and velocity are n_1, λ_1, I_1 and v_1 respectively. In water the corresponding quantities are n_2, λ_2, I_2 and v_2 respectively, then **[CBSE AIPMT 2001]**

(a) $I_1 = I_2$ (b) $n_1 = n_2$
(c) $v_1 = v_2$ (d) $\lambda_1 = \lambda_2$

Ans. *(b)*

When a wave enters from one medium to another, its frequency remains unchanged, i.e.

$n_1 = n_2$ but wavelength, intensity and velocity get changed.

16 Two strings A and B have lengths l_A and l_B and carry masses M_A and M_B at their lower ends, the upper ends being supported by rigid supports. If n_A and n_B are the frequencies of their vibrations and $n_A = 2n_B$, then **[CBSE AIPMT 2000]**

(a) $l_A = 4l_B$, regardless of masses
(b) $l_B = 4l_A$, regardless of masses
(c) $M_A = 2M_B, l_A = 2l_B$
(d) $M_B = 2M_A, l_B = 2l_A$

Ans. *(b)*

The frequency of vibrations of string is

$$n = \frac{1}{2}\sqrt{\frac{g}{l}} \quad ...(i)$$

Given, $n_A = 2n_B$

$$\therefore \quad \frac{1}{2}\sqrt{\frac{g}{l_A}} = 2\cdot\frac{1}{2}\sqrt{\frac{g}{l_B}}$$

or $$\frac{1}{l_A} = \frac{4}{l_B} \text{ or } l_B = 4l_A$$

It is obvious from Eq. (i), the frequency of vibrations of strings does not depend on their masses.

17 In a sinusoidal wave, the time required for a particular point, to move from maximum displacement to zero displacement is 0.170 s. The frequency of the wave is **[CBSE AIPMT 1998]**

(a) 1.47 Hz (b) 0.36 Hz
(c) 0.73 Hz (d) 2.94 Hz

Ans. *(a)*

If T is the time period, then time required for a point to move from maximum displacement to zero displacement is $\frac{T}{4}$.

So, $\frac{T}{4} = 0.170$ or $T = 0.170 \times 4 = 0.680$ s

Therefore, the frequency of wave is

$$n = \frac{1}{T} = \frac{1}{0.680} = 1.47\text{ Hz}$$

18 A transverse wave is represented by the equation

$$y = y_0\sin\frac{2\pi}{\lambda}(vt - x)$$

For what value of λ is the maximum particle velocity equal to two times the wave velocity ? **[CBSE AIPMT 1998]**

(a) $\lambda = 2\pi y_0$ (b) $\lambda = \frac{\pi y_0}{3}$
(c) $\lambda = \frac{\pi y_0}{2}$ (d) $\lambda = \pi y_0$

Ans. *(d)*

The given wave equation is

$$y = y_0\sin\frac{2\pi}{\lambda}(vt - x) \quad ...(i)$$

In the wave equation, v is the particle velocity.

Differentiating Eq. (i) with respect to time,

$$u = \frac{dy}{dt} = y_0\frac{2\pi v}{\lambda}\cos\frac{2\pi vt}{\lambda}$$

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Maximum particle velocity,

$$u_{max} = y_0 \frac{2\pi v}{\lambda}$$

Now, it is given that,

Maximum particle velocity = 2 × wave velocity

or $y_0 \frac{2\pi v}{\lambda} = 2v$ or $\lambda = \pi y_0$

19 The equation of a sound wave is given as $y = 0.005 \sin(62.4x + 316t)$. The wavelength of this wave is **[CBSE AIPMT 1996]**

(a) 0.4 unit (b) 0.3 unit
(c) 0.2 unit (d) 0.1 unit

Ans. *(d)*

Equation of plane progressive harmonic wave is

$$y = a \sin(\omega t + kx) \quad ...(i)$$

Given equation is

$$y = 0.005 \sin(62.4x + 316t) \quad ...(ii)$$

Comparing Eq. (ii) with Eq. (i),

$$\omega = 316, k = 62.4$$

$$\Rightarrow \quad k = \frac{2\pi}{\lambda} = 62.4$$

$$\therefore \quad \lambda = \frac{2\pi}{62.4} = \frac{2 \times 3.14}{62.4}$$

$$= 0.1 \text{ unit}$$

20 What is the effect of humidity on sound waves when humidity increases? **[CBSE AIPMT 1996]**

(a) Speed of sound waves increases
(b) Speed of sound waves decreases
(c) Speed of sound waves remains same
(d) Speed of sound waves becomes zero

Ans. *(a)*

The presence of water vapours in air changes its density. That is why the velocity of sound changes with humidity of air.

Suppose, ρ_m = density of moist air

ρ_d = density of dry air

v_m = velocity of sound in moist air

v_d = velocity of sound in dry air

Assuming that effect of humidity on γ is negligible.

As velocity of wave in a medium is given by

$$\therefore \quad v_m = \sqrt{\frac{\gamma p}{\rho_m}}$$

[γ = elasticity of medium
ρ_m = density of medium
p = pressure of sound waves]

and $v_d = \sqrt{\frac{\gamma p}{\rho_d}}$

Dividing, we get $\frac{v_m}{v_d} = \sqrt{\frac{\rho_d}{\rho_m}}$

The presence of water vapours reduces the density of air.

i.e. $\rho_m < \rho_d$

Hence, velocity of sound in moist air is greater, then the velocity of sound in dry air.

21 The speed of a wave in a medium is 760 m/s. If 3600 waves are passing through a point in the medium in 2 min, then their wavelength is **[CBSE AIPMT 1995]**

(a) 13.8 m (b) 25.3 m
(c) 41.5 m (d) 57.2 m

Ans. *(b)*

Given, speed of wave (v) = 760 m/s

Number of waves = 3600

Time, $t = 2 \text{ min} = 2 \times 60 = 120 \text{ s}$

$\therefore$ Frequency of waves,

$$\nu = \frac{\text{Total no. of waves}}{\text{time taken}} = \frac{3600}{120} = 30 \text{ Hz}$$

$\therefore$ Wavelength of waves

$$\lambda = \frac{v}{\nu} = \frac{760}{30} = 25.3 \text{ m}$$

22 A hospital uses an ultrasonic scanner to locate tumours in a tissue. The operating frequency of the scanner is 4.2 MHz. The speed of sound in a tissue is 1.7 km/s. The wavelength of sound in tissue is close to **[CBSE AIPMT 1995]**

(a) 4×10^{-4} m
(b) 8×10^{-4} m
(c) 4×10^{-3} m
(d) 8×10^{-3} m

Ans. *(a)*

Wavelength of a wave is the length of one wave. It is equal to the distance travelled by the wave during one complete cycle, wavelength of a wave is given by

$$\lambda = \frac{v}{\nu}$$

where v = velocity of wave (sound)

ν = frequency of wave (sound)

Given, $v = 1.7 \times 10^3 \text{ m/s}$

$\nu = 4.2 \times 10^6 \text{ Hz}$

$$\therefore \quad \lambda = \frac{1.7 \times 10^3}{4.2 \times 10^6} = 4 \times 10^{-4} \text{ m}$$

23 Two waves are said to be coherent, if they have **[CBSE AIPMT 1995]**

(a) same phase but different amplitude
(b) same frequency but different amplitude
(c) same frequency, phase and amplitude
(d) different frequency, phase and amplitude

Ans. *(c)*

Two wave are said to be coherent, when they have same frequency, amplitude and constant phase difference.

24 From a wave equation

$$y = 0.5 \sin \frac{2\pi}{3.2}(64t - x),$$

the frequency of the wave is **[CBSE AIPMT 1995]**

(a) 5 Hz (b) 15 Hz
(c) 20 Hz (d) 25 Hz

Ans. *(c)*

Standard equation of plane progressive harmonic wave is

$$y = a \sin \frac{2\pi}{\lambda}(vt - x) \quad ...(i)$$

Given equation is

$$y = 0.5 \sin \frac{2\pi}{3.2}(64t - x) \quad ...(ii)$$

Comparing Eq. (ii) with Eq. (i)

$$v = 64 \text{ and } \lambda = 3.2$$

$\therefore$ Frequency $\nu = \frac{v}{\lambda} = \frac{64}{3.2} = 20 \text{ Hz}$

25 If c_s be the velocity of sound in air and c be the rms velocity, then **[CBSE AIPMT 1994]**

(a) $c_s < c$ (b) $c_s = c$
(c) $c_s = c\left(\frac{\gamma}{3}\right)^{1/2}$ (d) None of these

Ans. *(c)*

Velocity of sound (c_s) is given by

$$c_s = \sqrt{\frac{\gamma p}{\rho}} \quad ...(i)$$

where, p is pressure, s is density and γ is atomicity of gas or ratio of C_p and C_v.

RMS velocity of gas molecules is given by

$$c = \sqrt{\left(\frac{3p}{\rho}\right)} \quad ...(ii)$$

From Eqs. (i) and (ii)

$$\frac{c_s}{c} = \sqrt{\frac{\gamma p}{\rho} \times \frac{\rho}{3p}} = \sqrt{\frac{\gamma}{3}}$$

$$\Rightarrow \quad c_s = c \times \sqrt{\left(\frac{\gamma}{3}\right)}$$

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26 Which of the following equation represents a wave ? **[CBSE AIPMT 1994]**

(a) $y = a\sin\omega t$
(b) $y = a\cos kx$
(c) $y = a\sin(\omega t - bx + c)$
(d) $y = a\sin(\omega t - kx)$

Ans. *(d)*

A wave equation travelling in +ve x direction is represented as

$$y = A\sin\omega\left(t - \frac{x}{v}\right)$$

y = displacement of wave at any time t
A = amplitude of wave
$\frac{x}{v}$ = time delay of motion of each particle

Other forms of wave equations are

$$y = A\sin(\omega t - kx)$$
$$= A\sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) = A\sin k(vt - x)$$

27 The frequency of sinusoidal wave, $0.40\cos(2000t + 0.80)$ would be **[CBSE AIPMT 1992]**

(a) 1000π Hz (b) 2000 Hz
(c) 20 Hz (d) $\frac{1000}{\pi}$ Hz

Ans. *(d)*

Equation of harmonic wave in cosine function is

$$y = a\cos(2\pi\nu t + \phi) \quad ...(i)$$

where, a = amplitude, ν = frequency and ϕ = phase

Given equation is

$$= 0.40\cos(2000t + 0.80) \quad ...(ii)$$

Comparing this equation with Eq. (i)

$$2\pi\nu = 2000$$
$$\therefore \quad \nu = \frac{2000}{2\pi} = \frac{1000}{\pi}\text{ Hz}$$

28 With the propagation of a longitudinal wave through a material medium, the quantities transmitted in the propagation direction are **[CBSE AIPMT 1992]**

(a) energy, momentum and mass
(b) energy
(c) energy and mass
(d) energy and linear momentum

Ans. *(b)*

In longitudinal waves, energy is propagated along with the wave motion without any net transport of the mass of the medium.

29 The transverse wave represented by the equation $y = 4\sin\frac{\pi}{6}\sin(3x - 15t)$ has **[CBSE AIPMT 1990]**

(a) amplitude $= 4\pi$
(b) wavelength $= \frac{4\pi}{3}$
(c) speed of propagation $= 5$
(d) period $= \frac{\pi}{15}$

Ans. *(c)*

The standard equation of transverse wave is

$$y = a\sin\left[\frac{2\pi t}{T} - \frac{2\pi x}{\lambda}\right] \quad ...(i)$$

Given equation is

$$y = 4\sin\frac{\pi}{6}\sin(15t - 3x) \quad ...(ii)$$

Comparing Eq. (ii) with Eq. (i)

$$\frac{2\pi}{\lambda} = 3,$$
$$\therefore \quad \lambda = \frac{2\pi}{3} \quad \text{and} \quad \frac{2\pi}{T} = 15$$
$$\therefore \quad T = \frac{2\pi}{15}$$

$\therefore$ Speed of propagation wave,

$$v = \frac{\lambda}{T} = \frac{2\pi/3}{2\pi/15} = 5$$

30 Velocity of sound waves in air is 330 m/s. For a particular sound wave in air, path difference of 40 cm is equivalent to phase difference of 1.6 π. The frequency of this wave is **[CBSE AIPMT 1990]**

(a) 165 Hz (b) 150 Hz
(c) 660 Hz (d) 330 Hz

Ans. *(c)*

At a given time (t = constant), the phase changes with position x. The phase change ($\Delta\phi$) at a given time for a wavelength (λ) for a distance Δx is given by

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x \quad ...(i)$$

From Eq. (i), $\Delta x = \frac{\lambda}{2\pi}\cdot\Delta\phi$ or $\lambda = 2\pi\cdot\frac{\Delta x}{\Delta\phi}$

Here, $\Delta x = 0.4$ m
$\Delta\phi = 1.6\ \pi$

$$\therefore \quad \lambda = 2\pi\cdot\frac{0.4}{1.6\pi} = 0.5$$

$\therefore$ Frequency of wave is

$$\nu = \frac{v}{\lambda} = \frac{330}{0.5} = 660\text{ Hz}$$

where, $v = 330$ m/s = velocity of sound

31 A 5.5 m length of string has a mass of 0.035 kg. If the tension in the string is 77 N, the speed of a wave on the string is **[CBSE AIPMT 1989]**

(a) 110 ms^{-1} (b) 165 ms^{-1}
(c) 77 ms^{-1} (d) 102 ms^{-1}

Ans. *(a)*

The velocity of propagation of a transverse wave on a stretched string is given by

$$v = \sqrt{\left(\frac{T}{\mu}\right)}$$

where T is tension in the string and μ is linear density of the string i.e. mass per unit length of the string.

Here, $\mu = \frac{0.035}{5.5}$ kg/m
$T = 77$ N

$$\therefore \quad v = \sqrt{\frac{77\times 5.5}{0.035}} = 110\text{ m/s}$$

32 If the amplitude of sound is doubled and the frequency reduced to one-fourth, the intensity of sound at the same point will **[CBSE AIPMT 1989]**

(a) increase by a factor of 2
(b) decrease by a factor of 2
(c) decrease by a factor of 4
(d) remains unchanged

Ans. *(c)*

Factors on which intensity depends are

(i) Amplitude (a) of vibration of the source, $I \propto a^2$
(ii) Surface area (A) of the vibrating body, $I \propto A$
(iii) Density (ρ) of the medium, $I \propto \rho$
(iv) Frequency (ν) of the source, $I \propto \nu^2$
(v) Motion of the medium which changes effective velocity v of sound, $I \propto v$

As $I \propto a^2$ and $I \propto \nu^2$

Therefore, intensity becomes $\frac{2^2}{4^2} = \frac{1}{4}$th.

33 The velocity of sound in any gas depends upon **[CBSE AIPMT 1988]**

(a) wavelength of sound
(b) density and elasticity of gas
(c) intensity of sound waves
(d) amplitude and frequency of sound

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Ans. *(b)*

From purely theoretical considerations, Newton came to the conclusion that velocity of longitudinal waves through any medium; solid, liquid or gas depends upon the elasticity and density of the medium. Newton gave the formula

$$v = \sqrt{\left(\frac{E}{\rho}\right)}$$

where v = velocity of sound in the medium

E = coefficient of elasticity in the medium

ρ = density of the (undisturbed) medium

34 Equation of progressive wave is given by

$$y = 4\sin\left[\pi\left(\frac{t}{5} - \frac{x}{9}\right) + \frac{\pi}{6}\right]$$

Then, which of the following is correct ? **[CBSE AIPMT 1988]**

(a) $v = 5$ cm (b) $\lambda = 18$ cm
(c) $a = 0.04$ cm (d) $f = 50$ Hz

Ans. *(b)*

Equation of plane progressive simple harmonic wave is

$$y = a\sin\left[2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) + \phi\right] \quad ...(i)$$

The given equation is

$$y = 4\sin\left[\pi\left(\frac{t}{5} - \frac{x}{9}\right) + \frac{\pi}{6}\right]$$

Multiplying and dividing $\left(\frac{t}{T} - \frac{x}{\lambda}\right)$ by 2.

It is written as,

$$y = 4\sin\left[2\pi\left(\frac{t}{10} - \frac{x}{18}\right) + \frac{\pi}{6}\right] \quad ...(ii)$$

Comparing Eqs. (i) and (ii), we find

$a = 4$ cm, $T = 10$ s, $\lambda = 18$ cm

and $\phi = \frac{\pi}{6}$

Hence option (b) is correct.

TOPIC 2
Superposition and Reflection of Waves

35 The length of the string of a musical instrument is 90 cm and has a fundamental frequency of 120 Hz. Where should it be pressed to produce fundamental frequency of 180 Hz? **[NEET (Oct.) 2020]**

(a) 75 cm (b) 60 cm
(c) 45 cm (d) 80 cm

Ans. *(b)*

Length of string of musical instrument,

$l = 90$ cm $= 0.9$ m

Fundamental frequency, $f_1 = 120$ Hz

$f_2 = 180$ Hz

$\therefore$ We know that $f \propto \frac{1}{l}$

$$\Rightarrow \quad \frac{f_1}{f_2} = \frac{l_2}{l_1} \Rightarrow l_2 = \frac{f_1 l_1}{f_2} = \frac{120 \times 0.9}{180}$$

$$= \frac{2}{3} \times 0.9 = 0.6 \text{ m} = 60 \text{ cm}$$

36 In a guitar, two strings A and B made of same material are slightly out of tune and produce beats of frequency 6 Hz. When tension in B is slightly decreased, the beat frequency increases to 7 Hz. If the frequency of A is 530 Hz, the original frequency of B will be **[NEET (Sep.) 2020]**

(a) 524 Hz (b) 536 Hz
(c) 537 Hz (d) 523 Hz

Ans. *(a)*

In case of beats formation unknown frequency $(\nu_B) = \nu_A \pm$ beats

where, $\nu_A = 530$ Hz and beats $= 6$ Hz.

$\Rightarrow \nu_B = 530 \pm 6 = 536$ or 524 Hz

When tension in B is slightly decreased, then beats frequency increases to 7 Hz. This is possible if we take original frequency of B as 524 Hz.

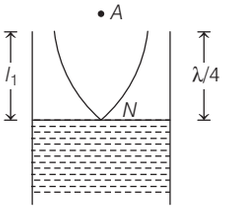
Hence, correct option is (a).

37 A tuning fork with frequency 800 Hz produces resonance in a resonance column tube with upper end open and lower end closed by water surface. Successive resonance are observed at length 9.75 cm, 31.25 cm and 52.75 cm. The speed of sound in air is **[NEET (Odisha) 2019]**

(a) 500 m/s (b) 156 m/s
(c) 344 m/s (d) 172 m/s

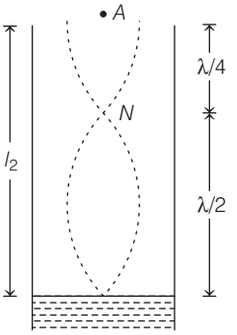
Ans. *(c)*

For vibrating tunning fork over a resonance tube, the first resonance is obtained at the length



$$l_1 = \frac{\lambda}{4} \quad ...(i)$$

and for second resonance,



$$l_2 = \frac{\lambda}{4} + \frac{\lambda}{2} = \frac{3\lambda}{4} \quad ...(ii)$$

From Eq. (i) and (ii), we get

$$l_2 - l_1 = \frac{3\lambda}{4} - \frac{\lambda}{4} = \frac{\lambda}{2}$$

$$\Rightarrow \quad \lambda = 2(l_2 - l_1)$$

$$\Rightarrow \quad v = 2f(l_2 - l_1) \quad ...(iii) \left(\because \lambda = \frac{v}{f}\right)$$

Here, $f = 800$ Hz, $l_1 = 9.75$ cm, $l_2 = 31.25$ cm

Substituting the given values in Eq. (iii), we get

$$\Rightarrow \quad v = 2 \times 800(31.25 - 9.75)$$

$$= 34400 \text{ cm/s} = 344 \text{ m/s}$$

38 The fundamental frequency in an open organ pipe is equal to the third harmonic of a closed organ pipe. If the length of the closed organ pipe is 20 cm, the length of the open organ pipe is **[NEET 2018]**

(a) 12.5 cm (b) 8 cm
(c) 13.3 cm (d) 16 cm

Ans. *(c)*

Fundamental frequency for an open organ pipe is given as

$$f_1 = \frac{v}{2L}$$

where, L is the length of the open organ pipe. Third harmonic for a closed organ pipe is given as

$$f' = \frac{3v}{4L'}$$

where, L' is the length of closed organ pipe. According to the question,

$$f = f'$$

$$\frac{v}{2L} = \frac{3v}{4L'}$$

$$L = \frac{2}{3}L'$$

Given, $L' = 20$ cm

$$\Rightarrow L = \frac{2}{3} \times 20 \text{ cm} = \frac{40}{3} \text{ cm} = 13.3 \text{ cm}$$

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39 A tuning fork is used to produce resonance in a glass tube. The length of the air column in this tube can be adjusted by a variable piston. At room temperature of 27°C, two successive resonances are produced at 20 cm and 73 cm of column length. If the frequency of the tuning fork is 320 Hz, the velocity of sound in air at 27°C is **[NEET 2018]**

(a) 350 m/s (b) 339 m/s
(c) 330 m/s (d) 300 m/s

Ans. *(b)*

For first resonance, $l_1 = \frac{\lambda}{4}$

For second resonance, $l_2 = \frac{3\lambda}{4}$

$\therefore \quad (l_2 - l_1) = \frac{3\lambda}{4} - \frac{\lambda}{4}$

or $\lambda = 2(l_2 - l_1)$ ...(i)

As, velocity of sound wave is given as,

$v = \nu\lambda$

where, ν is the frequency.

$\Rightarrow \quad v = \nu[2(l_2 - l_1)]$ [from Eq. (i)]

Here, $\nu = 320$ Hz, $l_2 = 0.73$ m, $l_1 = 0.20$ m

$\Rightarrow \quad v = 2[320(0.73 - 0.20)]$

$= 2 \times 320 \times 0.53$

$= 339.2 \text{ ms}^{-1} \simeq 339 \text{ ms}^{-1}$

40 The two nearest harmonics of a tube closed at one end and open at other end are 220 Hz and 260 Hz. What is the fundamental frequency of the system? **[NEET 2017]**

(a) 10 Hz (b) 20 Hz
(c) 30 Hz (d) 40 Hz

Ans. *(b)*

Thinking Process Frequency of nth harmonic in a closed end tube

$\Rightarrow \quad f = \frac{(2n-1)v}{4l} \qquad n = 1, 2, 3, \ldots$

Also, only odd harmonics exists in a closed end tube.

Now, given two nearest harmonics are of frequency 220 Hz and 260 Hz.

$\therefore \quad \frac{(2n-1)v}{4l} = 220 \text{ Hz}$ ...(i)

Next harmonic occurs at

$\frac{(2n+1)v}{4l} = 260 \text{ Hz}$ ...(ii)

On subtracting Eq. (i) from Eq. (ii), we get

$\frac{\{(2n+1) - (2n-1)\}v}{4l} = 260 - 220$

$2\left(\frac{v}{4l}\right) = 40 \Rightarrow \frac{v}{4l} = 20 \text{ Hz}$

$\therefore$ Fundamental frequency of the system

$= \frac{v}{4l} = 20 \text{ Hz}$

41 The second overtone of an open organ pipe has the same frequency as the first overtone of a closed pipe L metre long. The length of the open pipe will be **[NEET 2016]**

(a) L (b) $2L$
(c) $L/2$ (d) $4L$

Ans. *(b)*

For an open organ pipe,

$\nu_n = \frac{n}{2L}v$, where $n = 1, 2, 3, \ldots$

For second overtons $n = 3$, $v_{2O} = \frac{3}{2L_1}v$

L_1 = length of open organ pipe ...(i)

For closed organ pipe $\nu_n = \left(\frac{2n+1}{4L}\right)v$

where, $n = 0, 1, 2, 3, \ldots$

Ist overtone for closed organ pipe, $n = 1$

$\nu_{1_c} = \frac{3}{4L}v$ ...(ii)

$\because \quad \nu_{2_o} = \nu_{1_c} \Rightarrow \frac{3v}{2L_1} = \frac{3}{4L}v$

$\Rightarrow \quad L_1 = 2L$

42 Three sound waves of equal amplitudes have frequencies $(n-1)$, n, $(n+1)$. They superimpose to give beats. The number of beats produced per second will be **[NEET 2016]**

(a) 1 (b) 4
(c) 3 (d) 2

Ans. *(a)*

As we know that

Beat frequency $= f_1 \sim f_2 = n - (n-1) = 1$

and similarly for n and $n+1$

Beat frequency $= n + 1 - n = 1$

43 The fundamental frequency of a closed organ pipe of length 20 cm is equal to the second overtone of an organ pipe open at both the ends. The length of organ pipe open at both the ends is **[CBSE AIPMT 2015]**

(a) 80 cm (b) 100 cm
(c) 120 cm (d) 140 cm

Ans. *(c)*

The fundamental frequencies of closed and open organ pipe are givan as

$\nu_c = \frac{v}{4l} \Rightarrow \nu_o = \frac{v}{2l'}$

Given the second overtone (i.e. third harmonic) of open pipe is equal to the fundamental frequency of closed pipe

i.e. $3\nu_o = \nu_c$

$\Rightarrow \quad 3\frac{v}{2l'} = \frac{v}{4l}$

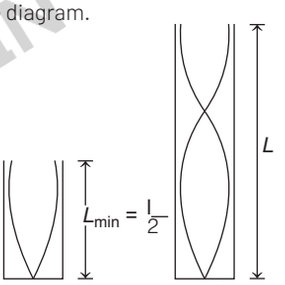
$\Rightarrow \quad l' = 6l = 6 \times 20 = 120 \text{cm}$

44 An air column, closed at one end and open at the other, resonates with a tunning fork when the smallest length of the column is 50 cm. The next larger length of the column resonating with the same tunning fork is **[CBSE AIPMT 2015]**

(a) 100 cm (b) 150 cm
(c) 200 cm (d) 66.7 cm

Ans. *(b)*

The smallest length of the air column is associated with fundamental mode of vibration of the air column as shown in the diagram.



$\because \quad L_{min} = \frac{\lambda}{4} \Rightarrow 50 \text{ cm} = \frac{\lambda}{4}$

$\Rightarrow \lambda = 200$ cm

The next higher length of the air column is

$L = \frac{\lambda}{4} + \frac{\lambda}{2} = \frac{\lambda + 2\lambda}{4} = \frac{3\lambda}{4}$

$= \frac{3}{4} \times 200 = 150 \text{ cm}$

45 A string is stretched between fixed points separated by 75.0 cm. It is observed to have resonant frequencies of 420 Hz and 315 Hz. There are no other resonant frequencies between these two. The lowest resonant frequency for this strings is **[CBSE AIPMT 2015]**

(a) 155 Hz (b) 205 Hz
(c) 10.5 Hz (d) 105 Hz

Ans. *(d)*

Given $l = 75$ cm, $f_1 = 420$ Hz and $f_2 = 315$ Hz.

As, two consecutive resonant frequencies for a string fixed at both ends will be

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$f_1 = \frac{nv}{2l}$ and $f_2 = \frac{(n+1)v}{2l}$

$\Rightarrow f_2 - f_1 = 420 - 315$

$\Rightarrow \frac{(n+1)v}{2l} - \frac{nv}{2l} = 105\,\text{Hz}$

$\Rightarrow \frac{v}{2l} = 105\,\text{Hz}$

Thus, lowest resonant frequency of a string is 105 Hz.

46 If n_1, n_2 and n_3 are the fundamental frequencies of three segments into which a string is divided, then the original fundamental frequency n of the string is given by **[CBSE AIPMT 2014]**

(a) $\frac{1}{n} = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3}$

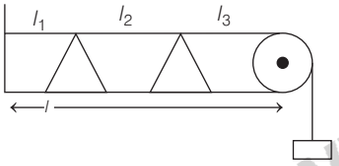
(b) $\frac{1}{\sqrt{n}} = \frac{1}{\sqrt{n_1}} + \frac{1}{\sqrt{n_2}} + \frac{1}{\sqrt{n_3}}$

(c) $\sqrt{n} = \sqrt{n_1} + \sqrt{n_2} + \sqrt{n_3}$

(d) $n = n_1 + n_2 + n_3$

Ans. *(a)*

Problem Solving Strategy In this problem, the fundamental frequencies of each part could be find. The fundamental frequency of the complete wire could be find. One should check each option for the given values.



For Ist part, $n_1 = \frac{v}{2l_1} \Rightarrow l_1 = \frac{v}{2n_1}$

For IInd part, $n_2 = \frac{v}{2l_2} \Rightarrow l_2 = \frac{v}{2n_2}$

For IIIrd part, $n_3 = \frac{v}{2l_3} \Rightarrow l_3 = \frac{v}{2n_3}$

For the complete wire, $n = \frac{v}{2l} \Rightarrow l = \frac{v}{2n}$

We have, $l = l_1 + l_2 + l_3$

$$\frac{v}{2n} = \frac{v}{2n_1} + \frac{v}{2n_2} + \frac{v}{2n_3}$$

$$\frac{1}{n} = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3}$$

47 The number of possible natural oscillations of air column in a pipe closed at one end of length 85 cm whose frequencies lie below 1250 Hz are (velocity of sound $= 340\ \text{ms}^{-1}$) **[CBSE AIPMT 2014]**

(a) 4 (b) 5 (c) 7 (d) 6

Ans. *(d)*

For pipe closed at one end,

$f_n = n\left(\frac{v}{4l}\right)$, here n is an odd number.

$$= n\left[\frac{340}{4 \times 85 \times 10^{-2}}\right] = n[100]$$

Here, n is an odd number, so for the given condition, n can go upto $n = 11$

i.e. $n = 1, 3, 5, 7, 9, 11$

So, number of possible natural oscillations could be 6. Which are below 1250 Hz.

48 If we study the vibration of a pipe open at both ends, which of the following statements is not true? **[NEET 2013]**

(a) Open end will be antinode

(b) Odd harmonics of the fundamental frequency will be generated

(c) All harmonics of the fundamental frequency will be generated

(d) Pressure change will be maximum at both ends

Ans.*(d)*

Statement (d) is not true, because at the open ends pressure change will be zero.

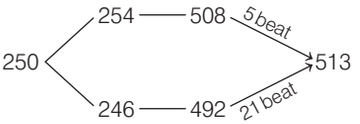
49 A source of unknown frequency gives 4 beat/s when sounded with a source of known frequency 250 Hz. The second harmonic of the source of unknown frequency gives 5 beat/s when sounded with a source of frequency 513 Hz. The unknown frequency is **[NEET 2013]**

(a) 254 Hz (b) 246 Hz

(c) 240 Hz (d) 260 Hz

Ans. *(a)*

Given,



Hence, unknown frequency is 254 Hz.

50 When a string is divided into three segments of lengths l_1, l_2 and l_3, the fundamental frequencies of these three segments are ν_1, ν_2 and ν_3 respectively. The original fundamental frequency (ν) of the string is **[CBSE AIPMT 2012]**

(a) $\sqrt{\nu} = \sqrt{\nu_1} + \sqrt{\nu_2} + \sqrt{\nu_3}$

(b) $\nu = \nu_1 + \nu_2 + \nu_3$

(c) $\frac{1}{\nu} = \frac{1}{\nu_1} + \frac{1}{\nu_2} + \frac{1}{\nu_3}$

(d) $\frac{1}{\sqrt{\nu}} = \frac{1}{\sqrt{\nu_1}} + \frac{1}{\sqrt{\nu_2}} + \frac{1}{\sqrt{\nu_3}}$

Ans. *(c)*

The fundamental frequency of string

$$\nu = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

$\therefore \quad \nu_1 l_1 = \nu_2 l_2 = \nu_2 l_3 = k$ ...(i)

From Eq. (i),

$$l_1 = \frac{k}{\nu_1}, l_2 = \frac{k}{\nu_2}, l_3 = \frac{k}{\nu_3}$$

Original length,

$$l = \frac{k}{\nu}$$

Here, $l = l_1 + l_2 + l_3$

$$\frac{k}{\nu} = \frac{k}{\nu_1} + \frac{k}{\nu_2} + \frac{k}{\nu_3}$$

$$\frac{1}{\nu} = \frac{1}{\nu_1} + \frac{1}{\nu_2} + \frac{1}{\nu_3}$$

51 Two sources of sound placed closed to each other, are emitting progressive waves given by $y_1 = 4\sin 600\pi t$ and $y_2 = 5\sin 608\pi t$ An observer located near these two sources of sound will hear **[CBSE AIPMT 2012]**

(a) 4 beat/s with intensity ratio 25 : 16 between waxing and waning

(b) 8 beat/s with intensity ratio 25 : 16 between waxing and waning

(c) 8 beat/s with intensity ratio 81 : 1 between waxing and waning

(d) 4 beat/s with intensity ratio 81 : 1 between waxing and waning

Ans. *(d)*

Given, $y_1 = 4\sin 600\,\pi t$

and $y_2 = 5\sin 608\,\pi t$

Comparing with general equation

$$y = a\sin 2\pi ft$$

We get, $f_1 = 300$ Hz

and $f_2 = 304$ Hz

So, number of beats $= f_2 - f_1 = 4\text{s}^{-1}$

We know that,

$$\frac{I_{\max.}}{I_{\min}} = \left(\frac{a_1 + a_2}{a_1 - a_2}\right)^2 = \left(\frac{4+5}{4-5}\right)^2 = 81$$

52 A tuning fork of frequency 512 Hz makes 4 beat/s with the vibrating string of a piano. The beat frequency decreases to 2 beat/s when the tension in the piano

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string is slightly increased. The frequency of the piano string before increasing the tension was **[CBSE AIPMT 2010]**

(a) 510 Hz (b) 514 Hz
(c) 516 Hz (d) 508 Hz

Ans. *(d)*

Let n_p be the frequency of piano

As $(n_p \propto \sqrt{T})$

n_f = frequency of tuning fork = 512 Hz

x = Beat frequency = 4 beats/s,

which is decreasing $(4 \rightarrow 2)$ after changing the tension of piano wire.

Also, tension of piano wire is increasing so $n_p \uparrow$

Hence, $n_p \uparrow - n_f = x \downarrow \longrightarrow$ wrong

$n_f - n_p \uparrow = x \downarrow \longrightarrow$ correct

$n_p = n_f - x = 512 - 4 = 508$ Hz

53 Two periodic waves of intensities I_1 and I_2 pass through a region at the same time in the same direction. The sum of the maximum and minimum intensities is **[CBSE AIPMT 2008]**

(a) $I_1 + I_2$ (b) $(\sqrt{I_1} + \sqrt{I_2})^2$
(c) $(\sqrt{I_1} - \sqrt{I_2})^2$ (d) $2(I_1 + I_2)$

Ans. *(d)*

As intensity is directly proportional to the square of amplitude

i.e. $I \propto a^2$

So, maximum intensity is given by

$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$

$[I_1, I_2$ are intensities of two waves$]$

and $I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$

$\therefore I_{max} + I_{min} = (\sqrt{I_1} + \sqrt{I_2})^2 + (\sqrt{I_1} - \sqrt{I_2})^2$

$= 2(I_1 + I_2)$

54 Two sound waves with wavelengths 5 m and 5.5 m respectively, each propagate in a gas with velocity 330 m/s. We expect the following number of beat per second **[CBSE AIPMT 2006]**

(a) 12 (b) zero (c) 1 (d) 6

Ans. *(d)*

Let $\lambda_1 = 5.0$ m, $v = 330$ m/s and $\lambda_2 = 5.5$ m

The relation between frequency (n), wavelength (λ) and velocity (v) is given by

$v = n\lambda$

$\Rightarrow \quad n = \frac{v}{\lambda}$ ....(i)

The frequency corresponding to wavelength λ_1,

$n_1 = \frac{v}{\lambda_1} = \frac{330}{5.0} = 66$ Hz

The frequency corresponding to wavelength λ_2,

$n_2 = \frac{v}{\lambda_2} = \frac{330}{5.5} = 60$ Hz

Hence, number of beats per second

$= n_1 - n_2 = 66 - 60 = 6$

55 Two vibrating tuning forks produce progressive waves given by $y_1 = 4 \sin 500\pi t$ and $y_2 = 2 \sin 506\pi t$. Number of beat produced per minute is **[CBSE AIPMT 2005]**

(a) 360 (b) 180 (c) 3 (d) 60

Ans. *(b)*

Given, $y_1 = 4 \sin 500\ \pi t$ ...(i)

$y_2 = 2 \sin 506\ \pi t$ ...(ii)

Comparing Eqs. (i) and (ii), we get

$y = a \sin \omega t$ ...(iii)

We have, $\omega_1 = 500\ \pi$

$\Rightarrow \quad n_1 = \frac{500\pi}{2\pi} = 250$ beats/s $\left[\because n = \frac{\omega}{2\pi}\right]$

and $\omega_2 = 506\ \pi$

$\Rightarrow \quad n_2 = \frac{506\ \pi}{2\pi} = 253$ beats/s

Thus, number of beats produced

$= n_2 - n_1 = 253 - 250 = 3$ beats/s

$= 3 \times 60$ beats/min $= 180$ beats/min

If equation of wave is given and to find physical quantities like amplitude, wavelength, time period, frequency, just compare the given equation with standard equation of wave.

56 Equations of two progressive waves are given by $y_1 = a \sin(\omega t + \phi_1)$ and $y_2 = a \sin(\omega t + \phi_2)$. If amplitude and time period of resultant wave are same as that of both the waves, then $(\phi_1 - \phi_2)$ is **[CBSE AIPMT 2001]**

(a) $\frac{\pi}{3}$ (b) $\frac{2\pi}{3}$ (c) $\frac{\pi}{6}$ (d) $\frac{\pi}{4}$

Ans. *(b)*

The given progressive waves are

$y_1 = a \sin(\omega t + \phi_1)$

$y_2 = a \sin(\omega t + \phi_2)$

The resultant of two waves is

$y = y_1 + y_2$

$= a[\sin(\omega t + \phi_1) + \sin(\omega t + \phi_2)]$

If A is the amplitude of resultant wave, then

$A = a$ (given)

$\therefore \quad A^2 = a^2 + a^2 + 2a^2 \cos\phi$

or $\quad a^2 = a^2 + a^2 + 2a^2 \cos\phi$

or $\quad \cos\phi = -\frac{1}{2} = \cos 120°$

$\therefore \quad \phi = 120° = \frac{2\pi}{3}$

Thus, $\quad \phi_1 - \phi_2 = \frac{2\pi}{3}$

57 A sonometer wire when vibrated in full length has frequency n. Now, it is divided by the help of bridges into a number of segments of lengths $l_1, l_2, l_3, \ldots$. When vibrated these segments have frequencies $n_1, n_2, n_3, \ldots$. Then, the correct relation is **[CBSE AIPMT 2000]**

(a) $n = n_1 + n_2 + n_3 + \ldots$

(b) $n^2 = n_1^2 + n_2^2 + n_3^2 + \ldots$

(c) $\frac{1}{n} = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} + \ldots$

(d) $\frac{1}{\sqrt{n}} = \frac{1}{\sqrt{n_1}} + \frac{1}{\sqrt{n_2}} + \frac{1}{\sqrt{n_3}} + \ldots$

Ans. *(c)*

From law of length, the frequency of vibrating string is inversely proportional to its length,

i.e. $n \propto \frac{1}{l}$

$[n$ = frequency of string
l = length of string$]$

or $\quad nl = \text{constant (say } k)$

or $\quad l = \frac{k}{n}$

The segments of string of length $l_1, l_2, l_3 \ldots$ have frequencies $n_1, n_2, n_3, \ldots$

Total length of string is l.

So, $\quad l = l_1 + l_2 + l_3 + \ldots$

$\therefore \quad \frac{k}{n} = \frac{k}{n_1} + \frac{k}{n_2} + \frac{k}{n_3} + \ldots$

or $\quad \frac{1}{n} = \frac{1}{n_1} + \frac{1}{n_2} + \frac{1}{n_3} + \ldots$

58 Two sources are at a finite distance apart. They emit sounds of wavelength λ. An observer situated between them on line joining approaches one source with speed u. Then, the number of beat heard/second by observer will be **[CBSE AIPMT 2000]**

(a) $\frac{2u}{\lambda}$ (b) $\frac{u}{\lambda}$ (c) $\frac{u}{2\lambda}$ (d) $\frac{\lambda}{u}$

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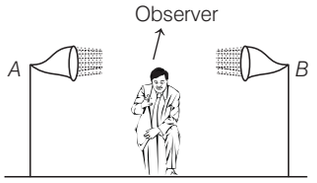
Ans. *(a)*

Let v be the speed of sound and n the original frequency of each source.

They emit sounds of wavelength λ.



When observer moves towards one source (say A), the apparent frequency of A as observed by the observer will be

$$n' = n\left(\frac{v+u}{v}\right)$$

[u = speed of observer towards A]

The observer is now receding source B, so the apparent frequency of B observed will be

$$n'' = n\left(\frac{v-u}{v}\right)$$

[u = speed of observer going away from B]

Thus, number of beats,

$$x = n' - n'' = n\left[\frac{v+u}{v} - \frac{v-u}{v}\right]$$

$$= \frac{n}{v}[v+u-v+u] = \frac{2nu}{v}$$

but $v = n\lambda$

Thus, $x = \frac{2nu}{n\lambda} = \frac{2u}{\lambda}$

59 Two waves of wavelength 50 cm and 51 cm produce 12 beat/s. The speed of sound is **[CBSE AIPMT 1999]**

(a) 306 m/s (b) 331 m/s
(c) 340 m/s (d) 360 m/s

Ans. *(a)*

Beats produced due to the two frequencies is given by

$$n_1 - n_2$$

where, n_1 and n_2 are the frequencies of two waves.

Here, number of beats = 12/s

$$\lambda_1 = 50\,\text{cm} = 0.50\,\text{m}$$

$$\lambda_2 = 51\,\text{cm} = 0.51\,\text{m}$$

$$n_1 - n_2 = 12$$

or $\frac{v}{\lambda_1} - \frac{v}{\lambda_2} = 12 \qquad \left[n = \frac{v}{\lambda}\right]$

or $v\left(\frac{\lambda_2 - \lambda_1}{\lambda_1\lambda_2}\right) = 12$

or $v = \frac{12\lambda_1\lambda_2}{\lambda_2 - \lambda_1}$

$\therefore$ v = speed of sound

$$= \frac{12 \times 0.50 \times 0.51}{(0.51 - 0.50)} = \frac{12 \times 0.50 \times 0.51}{0.01}$$

$= 306\,\text{m/s}$

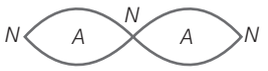
Thus, speed of sound is 306 m/s.

60 A standing wave having 3 node and 2 antinode is formed between two atoms having a distance 1.21 Å between them. The wavelength of the standing wave is **[CBSE AIPMT 1998]**

(a) 1.21 Å (b) 1.42 Å
(c) 6.05 Å (d) 3.63 Å

Ans. *(a)*

The given standing wave is shown in the figure.



As length of one loop or segment is $\frac{\lambda}{2}$, so length of 2 segments is $2\left(\frac{\lambda}{2}\right)$.

So, according to question

$\therefore$ $2\frac{\lambda}{2} = 1.21\,\text{Å} \Rightarrow \lambda = 1.21\,\text{Å}$

61 A cylindrical resonance tube open at both ends, has a fundamental frequency f, in air. If half of the length is dipped vertically in water, the fundamental frequency of the air column will be **[CBSE AIPMT 1997]**

(a) $2f$ (b) $\frac{3f}{2}$ (c) f (d) $\frac{f}{2}$

Ans. *(c)*

Fundamental frequency of open pipe,

$$f = \frac{v}{2l} \qquad \ldots(i)$$

$\left[\begin{matrix} v = \text{velocity of wave} \\ l = \text{length of open pipe} \end{matrix}\right]$

When half length of tube is dipped vertically in water, then length of the air column becomes half $\left(l' = \frac{l}{2}\right)$ and the pipe becomes closed.

So, new fundamental frequency of closed pipe

$$f' = \frac{v}{4l}, = \frac{v}{4\left(\frac{l}{2}\right)} = \frac{v}{2l} \qquad \ldots(ii)$$

From Eqs. (i) and (ii), we get,

$$f' = f$$

Hence, there will be no change in fundamental frequency.

62 A pulse of a wave train travels along a stretched string and reaches the fixed end of the string. It will be reflected back with **[CBSE AIPMT 1997]**

(a) a phase change of 180° with velocity reversed
(b) the same phase as the incident pulse with no reversal of velocity
(c) a phase change of 180° with no reversal of velocity
(d) the same phase as the incident pulse but with velocity reversed

Ans. *(a)*

A pulse of a wave train when travels along a stretched string and reaches the fixed end of the string, then it will be reflected back to the same medium and the reflected ray suffers a phase change of π with the incident wave and wave velocity after reflection will reverse.

63 Standing waves are produced in a 10 m long stretched string. If the string vibrates in 5 segments and the wave velocity is 20 m/s, the frequency is **[CBSE AIPMT 1997]**

(a) 10 Hz (b) 5 Hz (c) 4 Hz (d) 2 Hz

Ans. *(b)*

In the case of standing wave, the length of one segment is $\frac{\lambda}{2}$. There are 5 segments and total length of string is 10 m.

$\therefore$ $5\frac{\lambda}{2} = 10 \Rightarrow \lambda = 4\,\text{m}$

Frequency, $n = \frac{v}{\lambda} = \frac{20}{4} = 5\,\text{Hz}$

$(\because v = 20\,\text{m/s})$

Standing wave is an example of interference. Destructive interference means node and constructive interference means antinode.

64 Two waves of same frequency and intensity superimpose on each other in opposite phases. After the superposition, the intensity and frequency of waves will **[CBSE AIPMT 1996]**

(a) increase (b) decrease
(c) remain constant (d) become zero

Ans. *(d)*

Interference phenomenon is common to sound and light. In sound, the interference is said to be constructive at points where resultant intensity is maximum (are in phase) and destructive at points where resultant intensity is minimum or zero (are in opposite phase).

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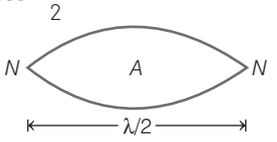
65 Two waves are approaching each other with a velocity of 20 m/s and frequency *n*. The dist nodes is **[CBSE AIPMT 1995]**

(a) $\frac{20}{n}$ (b) $\frac{10}{n}$ (c) $\frac{5}{n}$ (d) $\frac{n}{10}$

Ans. *(b)*

Distance between two successive nodes $= \frac{\lambda}{2}$



but we know that, $v = \nu\lambda$

$\therefore \quad \frac{\lambda}{2} = \frac{v}{2\nu}$

Given, $v = 20$ m/s

frequency, $\nu = n$

So, $\frac{\lambda}{2} = \frac{20}{2n} = \frac{10}{n}$

66 A wave of frequency 100 Hz is sent along a string towards a fixed end. When this wave travels back after reflection, a node is formed at a distance of 10 cm from the fixed end of the string. The speed of incident (and reflected) wave are **[CBSE AIPMT 1994]**

(a) 5 m/s (b) 10 m/s
(c) 20 m/s (d) 40 m/s

Ans. *(c)*

As fixed end is a node, therefore distance between two consecutive nodes

$= \frac{\lambda}{2} = 10$ cm

[λ = wavelength of wave sent]

$\Rightarrow \quad \lambda = 20\,\text{cm} = 0.2\,\text{m}$

As we know, $v = \nu\lambda$

[v = velocity of wave, ν = frequency of wave]

$\therefore \quad v = 100 \times 0.2 = 20\,\text{m/s}$

67 A standing wave is represented by $y = a\sin(100t)\cos(\mathbf{0.01})x$, where y and a are in millimetre, t in second and x is in metre. Velocity of wave is **[CBSE AIPMT 1994]**

(a) 10^4 m/s (b) 1 m/s
(c) 10^{-4} m/s (d) None of these

Ans. *(a)*

The standard equation of standing wave is

$y = a\sin(\omega t)\cos(kx)$ ...(i)

Given equation is

$y = a\sin(100t)\cos(0.01x)$ ...(ii)

Comparing Eqs. (i) and (ii)

$\omega = 100$ and $k = 0.01$

$\therefore$ Velocity of wave is

$$v = \frac{\lambda}{T} = \frac{\omega}{k} = \frac{100}{0.01} \quad \left[\text{As, } \omega = \frac{2\pi}{T} \text{ and } k = \frac{2\pi}{\lambda}\right]$$

$= 10^4$ m / s

68 A stretched string resonates with tuning fork of frequency 512 Hz when length of the string is 0.5 m. The length of the string required to vibrate resonantly with a tuning fork of frequency 256 Hz would be **[CBSE AIPMT 1993]**

(a) 0.25 m (b) 0.5 m (c) 1 m (d) 2 m

Ans. *(c)*

The frequency of fundamental note of the stretched string is given by

$$\nu = \frac{1}{2L}\sqrt{\left(\frac{T}{\mu}\right)} \quad ...(i)$$

where, T is tension in string and μ is mass per unit length of the string.

From Eq. (i) $\nu \propto \frac{1}{L}$

[As string is same so μ will be same]

For two different case

$\therefore \quad \frac{\nu_1}{\nu_2} = \frac{L_2}{L_1}$

Here, $\nu_1 = 512$ Hz, $L_1 = 0.5$ m

$\nu_2 = 256$ Hz, $L_2 = ?$

$\therefore \quad \frac{512}{256} = \frac{L_2}{0.5}$

$\Rightarrow \quad L_2 = 0.5 \times 2 = 1\,\text{m}$

69 For production of beats the two sources must have **[CBSE AIPMT 1992]**

(a) different frequencies and same amplitude
(b) different frequencies
(c) ifferent frequencies, same amplitude and same phase
(d) different frequencies and same phase

Ans. *(b)*

When two sound waves of slightly different frequencies travel in a medium along the same direction and superimpose on each other, intensity of the resultant sound at a particular position rises and falls alternately with time. This phenomenon of alternate variation in the intensity of sound with time at a particular position, when two sound waves of nearly equal frequencies (but not equal) superimpose on each other is called beats.

70 A closed organ pipe (closed at one end) is excited to support the third overtone. It is found that air in the pipe has **[CBSE AIPMT 1991]**

(a) three nodes and three antinodes
(b) three nodes and four antinodes
(c) four nodes and three antinodes
(d) four nodes and four antinodes

Ans. *(d)*

In a closed organ pipe, only alternate harmonics of frequencies $\nu_1, 3\nu_1, 5\nu_1, \ldots$ etc are present. The harmonics of frequencies $2\nu_1, 4\nu_1, 6\nu_1, \ldots$ are missing. In general, the frequency of note produced in nth normal mode of vibration of closed organ pipe would be

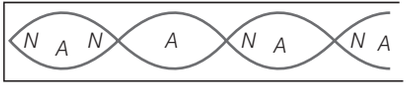
$$\nu_n = \frac{(2n-1)v}{4L} = (2n-1)\,\nu_1$$

This is $(2n-1)$ th harmonic or $(n-1)$ th overtone.

Third overtone has a frequency $7\nu_1$, which means

$$L = \frac{7\lambda}{4} = \frac{\lambda}{2} + \frac{\lambda}{2} + \frac{\lambda}{2} + \frac{\lambda}{4}$$

hich is three full loops and a half loop, which is equal to four nodes and four antinodes.



TOPIC 3
Doppler Effect

71 Two cars moving in opposite directions approach each other with speed of 22 m/s and 16.5 m/s respectively. The driver of the first car blows a horn having a frequency 400 Hz. The frequency heard by the driver of the second car is [velocity of sound 340 m/s] **[NEET 2017]**

(a) 350 Hz (b) 361 Hz
(c) 411 Hz (d) 448 Hz

Ans. *(d)*

Thinking Process When both source and observer are moving towards each other, apparent frequency is given by

$$f_a = f_0\left(\frac{v + v_0}{v - v_s}\right)$$

where, f_0 = original frequency of source

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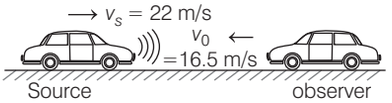
v_s = speed of source
v_0 = speed of observer
v = speed of sound
Frequency of the horn,
$f_0 = 400$ Hz
Speed of observer in the second car,
$v_0 = 16.5$ m/s
$\longrightarrow v_S = 22$ m/s



Speed of source,
v_s = speed of first car
= 22 m/s
Frequency heard by the driver in the second car

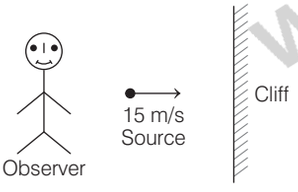
$$f_a = f_0\left(\frac{v+v_0}{v-v_s}\right) = 400\left(\frac{340+16.5}{340-22}\right)$$
$$= 448 \text{ Hz}$$

72 A siren emitting a sound of frequency 800 Hz moves away from an observer towards a cliff at a speed of 15 ms^{-1}. Then, the frequency of sound that the observer hears in the echo reflected from the cliff is (Take, velocity of sound in air = 330 ms^{-1}) **[NEET 2016]**

(a) 800 Hz (b) 838 Hz
(c) 885 Hz (d) 765 Hz

Ans. *(b)*

According to question, situation can be drawn as follows



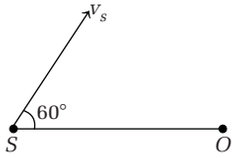
Frequency of sound that the observer hear in the echo reflected from the cliff is given by

$$f' = \left(\frac{v}{v-v_s}\right)$$

where f = original frequency of source;
v = velocity of sound
v_s = velocity of source

So, $f' = \left(\frac{330}{330-15}\right)800 = 838$ Hz

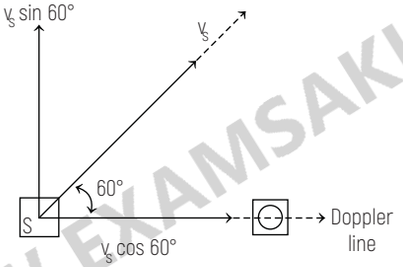
73 A source of sound S emitting waves of frequency 100 Hz and an observer O are located at some distance from each other. The source is moving with a speed of 19.4 ms^{-1} at an angle of 60° with the source observer line as shown in the figure. The observer is at rest. The apparent frequency observed by the observer (velocity of sound in air is 330 ms^{-1}), is **[CBSE AIPMT 2015]**



(a) 100 Hz (b) 103 Hz
(c) 106 Hz (d) 97 Hz

Ans. *(b)*

Given, as a source of sound S emitting waves of frequency 100 Hz and an observer O are located at some distance. Such that, source is moving with a speed of 19.4 m/s at angle 60° with source-observer line as shown in figure.



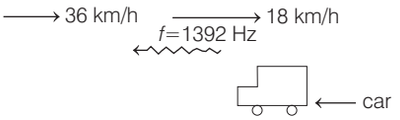
The apparent frequency heared by observer

$$f_0 = f_s\left[\frac{v}{v - v_s\cos 60°}\right]$$
$$= 100\left[\frac{330}{330 - 19.4\times\frac{1}{2}}\right]$$
$$= 100\left[\frac{330}{300-9.7}\right] = 100\left[\frac{330}{320.3}\right]$$
$$= 103.02 \text{ Hz}$$

74 A speeding motorcyclist sees traffic jam ahead of him. He slows down to 36 km/h. He finds that traffic has eased and a car moving ahead of him at 18 km/h is honking at a frequency of 1392 Hz. If the speed of sound is 343 m/s, the frequency of the honk as heard by him will be **[CBSE AIPMT 2014]**

(a) 1332 Hz (b) 1372 Hz
(c) 1412 Hz (d) 1454 Hz

Ans. *(c)*



⇒ As both observer and source are moving, we can use the formula of apparent frequency as

$$f = f_0\left(\frac{v+v_0}{v+v_s}\right)$$
$$= 1392\left[\frac{343+10}{343+5}\right]$$

[$\because v_0 = 36$ km / h = 10 m / s and $v_s = 18$ km / h = 5 m / s]

$$= 1392\left[\frac{353}{348}\right] = 1412 \text{ Hz}$$

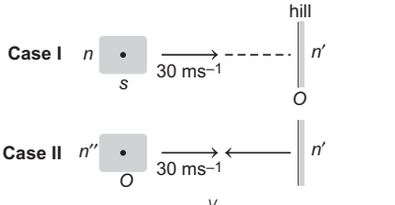
75 The driver of a car travelling with speed 30 ms^{-1} towards a hill sounds a horn of frequency 600 Hz. If the velocity of sound in air is 330 ms^{-1}, the frequency of reflected sound as heard by driver is **[CBSE AIPMT 2009]**

(a) 550 Hz
(b) 555.5 Hz
(c) 720 Hz
(d) 500 Hz

Ans. *(c)*

Concept Use Doppler's effect.

According to Doppler's effect, whenever there is a relative motion between a source of sound and the observer (listener), the frequency of sound heard by the observer is different from the actual frequency of sound emitted by source.



[for case I] $n' = \frac{v}{v-30}n$ ...(i)

[n = frequency emitted by car
v = velocity of sound]

[for case II] $n'' = \frac{v+30}{v}n'$ ...(ii)

[n'' = frequency heard by the driver after reflection]

From Eqs. (i) and (ii), we get

$$n'' = \frac{v+30}{v-30}n = \frac{360}{300}\times 600 = 720 \text{ Hz}$$

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76 A car is moving towards a high cliff. The car driver sounds a horn of frequency f. The reflected sound heard by the driver has a frequency $2f$. If v be the velocity of sound, then the velocity of the car, in the same velocity units, will be **[CBSE AIPMT 2004]**

(a) $\frac{v}{\sqrt{2}}$ (b) $\frac{v}{3}$ (c) $\frac{v}{4}$ (d) $\frac{v}{2}$

Ans. ***(b)***

When the sound is reflected from the cliff, it approaches the driver of the car. Therefore, the driver acts as an observer and both the source (car) and observer are moving.

Hence, apparent frequency heard by the observer (driver) is given by

$$f' = f\left(\frac{v + v_o}{v - v_s}\right) \quad \text{...(i)}$$

where, v = velocity of sound,

v_o = velocity of car = v_s

Thus, Eq. (i) becomes

$$\therefore \quad 2f = f\left(\frac{v + v_o}{v - v_o}\right)$$

or $2v - 2v_o = v + v_o$

or $3v_o = v$ or $v_o = \frac{v}{3}$

77 An observer moves towards a stationary source of sound with a speed 1/ 5th of the speed of sound. The wavelength and frequency of the source emitted are λ and f respectively. The apparent frequency and wavelength recorded by the observer are respectively **[CBSE AIPMT 2003]**

(a) $f, 1.2\lambda$ (b) $0.8f, 0.8\lambda$

(c) $1.2f, 1.2\lambda$ (d) $1.2f, \lambda$

Ans. ***(d)***

When an observer moves towards a stationary source of sound, then apparent frequency heard by the observer increases. The apparent frequency heard in this situation

$$f' = \left(\frac{v + v_o}{v - v_s}\right) f$$

As source is stationary hence, $v_s = 0$

$$\therefore \quad f' = \left(\frac{v + v_o}{v}\right) f$$

Given, $v_o = \frac{v}{5}$

Substituting in the relation for f', we have

$$f' = \left(\frac{v + v/5}{v}\right) f = \frac{6}{5} f = 1.2f$$

Motion of observer does not affect the wavelength reaching the observer, hence, wavelength remains λ.

78 A whistle revolves in a circle with angular velocity $\omega = 20$ rad/s using a string of length 50 cm. If the actual frequency of sound from the whistle is 385 Hz, then the minimum frequency heard by the observer far away from the centre is (velocity of sound $v = 340$ m/s) **[CBSE AIPMT 2002]**

(a) 385 Hz (b) 374 Hz

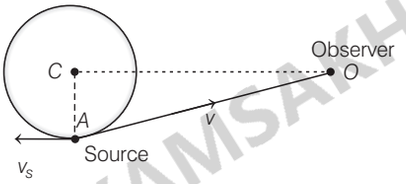
(c) 394 Hz (d) 333 Hz

Ans. ***(b)***

Velocity of source (whistle) is given by

$$v_s = r\omega = (0.5\text{ m})(20\text{ rad/s})$$
$$= 10\text{ m/s}$$

The frequency of sound observed by the observer will be minimum when he is at point A. Thus, at this point minimum frequency of source as observed by observer is



$$f_{min} = \left(\frac{v}{v + v_s}\right) n$$

$$f_{min} = \frac{340}{340 + 10} \times 385$$

$$= \frac{34}{35} \times 385 = 34 \times 11 = 374\text{ Hz}$$

79 A vehicle, with a horn of frequency n is moving with a velocity of 30 m/s in a direction perpendicular to the straight line joining the observer and the vehicle. The observer perceives the sound to have a frequency $n + n_1$. Then (If the sound velocity in air is 300 m/s) **[CBSE AIPMT 1998]**

(a) $n_1 = 10n$ (b) $n_1 = 0$

(c) $n_1 = 0.1n$ (d) $n_1 = -0.1n$

Ans. ***(b)***

When velocity of source (vehicle) is perpendicular to the line joining the observer and source, then there is no Doppler effect of sound as the component of velocity either towards or away from the observer is zero. So, there is no change in apparent frequency. Therefore, $n_1 = 0$.

80 A star which is emitting radiation at a wavelength of 5000 Å is approaching the earth with a velocity of $\mathbf{1.50} \times 10^6$ m/s. The change in wavelength of the radiation as received on the earth is **[CBSE AIPMT 1996]**

(a) 0.25 Å (b) 2.5 Å (c) 25 Å (d) 250 Å

Ans. ***(c)***

The phenomenon of apparent change in frequency (or wavelength) of the light due to the relative motion between the source of light and the observer is called Doppler effect in light.

So, $$\Delta\lambda = \lambda \times \frac{v}{c} \quad \text{...(i)}$$

Given, wavelength $\lambda = 5000$ Å

Velocity of source $= 1.5 \times 10^6$ m/s

$c = 3 \times 10^8$ m/s

$$\therefore \quad \Delta\lambda = 5000 \times \frac{1.5 \times 10^6}{3 \times 10^8} = 25\text{Å}$$

81 Two trains move towards each other with the same speed. The speed of sound is 340 m/s. If the height of the tone of the whistle of one of them heard on the other changes 9/8 times, then the speed of each train should be **[CBSE AIPMT 1991]**

(a) 20 m/s (b) 2 m/s

(c) 200 m/s (d) 2000 m/s

Ans. ***(a)***

According to Doppler's effect, whenever there is a relative motion between a source of sound and listener, the apparent frequency of sound heard by the listener is different from the actual frequency of sound emitted by the source.

Apparent frequency of sound wave heard by the listener is

$$\nu' = \frac{v - v_l}{v - v_s} \times \nu$$

where, ν is actual frequency of sound emitted by the source, v_s is velocity of source and v_l is velocity of listener.

According to problem, $\nu' = (9/8)\,\nu$ and source and observer are moving in opposite directions with same speed (say v), then apparent frequency

$$\nu' = \nu \times \left(\frac{v + v_l}{v - v_s}\right)$$

$$\therefore \quad \frac{9}{8}\nu = \nu \times \frac{340 + v}{340 - v}$$

$$\therefore \quad 17v = 340$$

or $$v = \frac{340}{17} = 20\text{ m/s}$$

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15

Electric Charges and Fields

TOPIC 1
Electric Charges and Coulomb's Law

01 The acceleration of an electron due to the mutual attraction between the electron and a proton when they are 1.6 Å apart is,
($m_e \simeq 9\times10^{-31}$ kg, $e = 1.6\times10^{-19}$ C)
$\left(\text{take}, \frac{1}{4\pi\varepsilon_0} = 9\times10^9\ \text{Nm}^2\text{C}^{-2}\right)$

[NEET (Oct.) 2020]

(a) 10^{24} m/s^2 (b) 10^{23} m/s^2
(c) 10^{22} m/s^2 (d) 10^{25} m/s^2

Ans. *(c)*

Force of mutual attraction between the electron and proton.
(when, $r = 1.6\ \text{A}^\circ = 1.6\times10^{-10}$ m) is given as

$$F = 9\times10^9\times\frac{e^2}{r^2}$$
$$= 9\times10^9\times\frac{(1.6\times10^{-19})^2}{(1.6\times10^{-10})^2}$$
$$= 9\times10^{-9}\ \text{N}$$

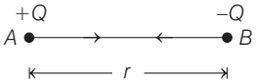
$\therefore$ Acceleration of electron
$$= \frac{F}{m_e} = \frac{9\times10^{-9}}{9\times10^{-31}} = 10^{22}\ \text{m/s}^2$$

02 Two point charges A and B, having charges $+Q$ and $-Q$ respectively, are placed at certain distance apart and force acting between them is F. If 25% charge of A is transferred to B, then force between the charges becomes **[NEET (National) 2019]**

(a) $\frac{9F}{16}$ (b) $\frac{16F}{9}$ (c) $\frac{4F}{3}$ (d) F

Ans. *(a)*

The force between two point charges A and B having charge $+Q$ and $-Q$ respectively is given by



$$F = \frac{K\,Q_A Q_B}{r^2} = \frac{KQ(-Q)}{r^2} = -\frac{KQ^2}{r^2} \quad ...(i)$$

where, K = constant $= \frac{1}{4\pi\varepsilon_0}$

and r = distance between two charges A and B.

When 25% charge of A is transferred to B, then new amount of charge on A and B respectively become

$$Q'_A = \frac{75}{100}(Q_A) = \frac{3}{4}Q$$
$$Q'_B = \left(\frac{25}{100}Q_A + Q_B\right) = \left(\frac{1}{4}Q - Q\right) = \frac{-3}{4}Q$$

So, the force between the two charges now becomes

$$F' = \frac{K\,Q'_A\,Q'_B}{r^2} = \frac{K\left(\frac{3Q}{4}\right)\left(-\frac{3}{4}Q\right)}{r^2}$$
$$= \frac{-9KQ^2}{16r^2} = \frac{9}{16}F \qquad [\text{from Eq. (i)}]$$

Thus, the new force between the charges is 9/16 time the initial force between the charges.

03 Suppose the charge of a proton and an electron differ slightly. One of them is $-e$ and the other is $(e + \Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order [Given mass of hydrogen, $m_h = 1.67\times10^{-27}$ kg] **[NEET 2017]**

(a) 10^{-20} C (b) 10^{-23} C
(c) 10^{-37} C (d) 10^{-47} C

Ans. *(c)*

Net charge on one H-atom
$$q = -e + e + \Delta e = \Delta e$$
Net electrostatic repulsive force between two H-atoms
$$F_r = \frac{Kq^2}{d^2}$$
$$= \frac{K(\Delta e)^2}{d^2}$$

Similarly, net gravitational attractive force between two H-atoms
$$F_G = \frac{Gm_r^2}{d^2}$$

It is given that, $F_r - F_G = 0$
$$\Rightarrow \quad \frac{K(\Delta e)^2}{d^2} - \frac{Gm_r^2}{d^2} = 0$$
$$\Rightarrow \quad (\Delta e)^2 = \frac{Gm_r^2}{K}$$
$$(\Delta e)^2 = \frac{(6.67\times10^{-11})\,(1.67\times10^{-27})^2}{9\times10^9}$$
$$\Rightarrow \quad \Delta e = 1.437\times10^{-37}\ \text{C}$$

04 Two identical charged spheres suspended from a common point by two massless strings of lengths l, are initially at a distance d ($d << l$) apart because of their mutual repulsion. The charges begin to leak from both the spheres at a constant rate. As a result, the spheres approach each other with

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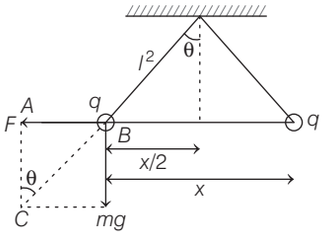
a velocity v. Then, v varies as a function of the distance x between the sphere, as **[NEET 2016]**

(a) $v \propto x$ (b) $v \propto x^{-\frac{1}{2}}$

(c) $v \propto x^{-1}$ (d) $v \propto x^{\frac{1}{2}}$

Ans. *(b)*

According to question, two identical charged spheres suspended from a common point by two massless strings of length L.



$\because$ In ΔABC

$$\tan\theta = \frac{F}{mg} \quad \text{or} \quad \frac{F}{mg} = \tan\theta \quad ...(i)$$

Since, the charges begins to leak from both the spheres at a constant rate. As a result, the spheres approach each other with velocity v.

Therefore, Eq. (i) can be rewritten as

$$\frac{Kq^2}{x^2 mg} = \frac{x/2}{\sqrt{l^2 - \frac{x^2}{4}}}$$

$$\Rightarrow \quad \frac{Kq^2}{x^2 mg} = \frac{x}{2l} \quad \text{or} \quad q^2 \propto x^3$$

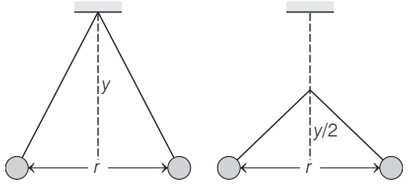
$$\Rightarrow \quad q \propto x^{3/2}$$

$$\Rightarrow \quad \frac{dq}{dt} \propto \frac{d(x^{3/2})}{dx} \cdot \frac{dx}{dt}$$

$$\Rightarrow \quad \frac{dq}{dt} \propto x^{1/2}.v$$

$$\Rightarrow \quad v \propto \frac{1}{x^{1/2}} \quad \text{or} \quad v \propto x^{-1/2}$$

05 Two pith balls carrying equal charges are suspended from a common point by strings of equal length, the equilibrium separation between them is r. Now, the strings are rigidly clamped at half the height. The equilibrium separation between the balls now becomes **[NEET 2013]**

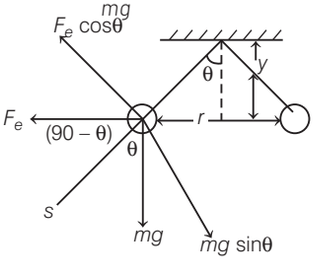


(a) $\left(\frac{1}{\sqrt{2}}\right)^2$ (b) $\left(\frac{r}{\sqrt{2}}\right)$ (c) $\left(\frac{2r}{\sqrt{3}}\right)$ (d) $\left(\frac{2r}{3}\right)$

Ans. *(b)*

Case I $F_e \cos\theta = mg \sin\theta$

$$\Rightarrow \quad \frac{F_e}{mg} = \tan\theta$$



$$\Rightarrow \quad mg = \frac{F_e}{\tan\theta} \quad ...(i)$$

***Case* II** $F_e' \cos\theta_1 = mg \sin\theta_1$

$$\Rightarrow \quad \frac{F_e'}{mg} = \tan\theta_1$$

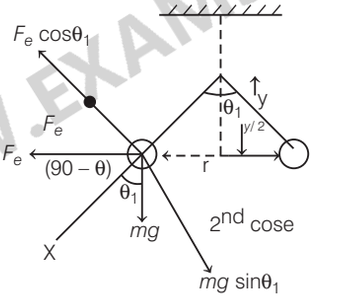
$$\Rightarrow \quad mg = \frac{F_e'}{\tan\theta_1} \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\frac{F_e}{\tan\theta} = \frac{F_e'}{\tan\theta_1} \Rightarrow \frac{F_e}{F_e'} = \frac{\tan\theta}{\tan\theta_1}$$

As, $\tan\theta = \frac{P(\text{perpendicular})}{b(\text{base})} = \frac{r}{2y}$

$$\tan\theta_1 = P/b = \frac{r}{2 \times y} \times 2 = \frac{r}{y}$$



$$\frac{F_e}{F_e'} = \frac{r}{2y \times r} \times y \Rightarrow F_e' = 2F_e$$

So, $\frac{kq^2}{r'^2} = \frac{2kq^2}{r^2} \Rightarrow \frac{1}{r'} = \frac{\sqrt{2}}{r}$

$\therefore \quad r' = \frac{r}{\sqrt{2}}$

06 Two positive ions, each carrying a charge q, are separated by a distance d. If F is the force of repulsion between the ions, the number of electrons missing from each ion will be (e being the charge on an electron) **[CBSE AIPMT 2010]**

(a) $\frac{4\pi\varepsilon_0 Fd^2}{e^2}$ (b) $\sqrt{\frac{4\pi\varepsilon_0 Fe^2}{d^2}}$

(c) $\sqrt{\frac{4\pi\varepsilon_0 Fd^2}{e^2}}$ (d) $\frac{4\pi\varepsilon_0 Fd^2}{q^2}$

Ans. *(c)*

Two positive ions each carrying a charge q are kept at a distance d, then it is found that force of repulsion between them is

$$F = \frac{kqq}{d^2} = \frac{1}{4\pi\varepsilon_0}\frac{qq}{d^2}$$

where, $q = ne$

$\therefore \quad F = \frac{1}{4\pi\varepsilon_0}\frac{n^2 e^2}{d^2}$

$\Rightarrow \quad n = \sqrt{\frac{4\pi\varepsilon_0 Fd^2}{e^2}}$

07 An electron is moving round the nucleus of a hydrogen atom in a circular orbit of radius r. The coulomb force $\mathbf{F}$ between the two is **[CBSE AIPMT 2003]**

(a) $k\frac{e^2}{r^3}\mathbf{r}$ (b) $-k\frac{e^2}{r^3}\mathbf{r}$

(c) $k\frac{e^2}{r^2}\hat{\mathbf{r}}$ (d) $-k\frac{e^2}{r^3}\hat{\mathbf{r}}$

(where, $k = \frac{1}{4\pi\varepsilon_0}$)

Ans. *(b)*

Let charges on an electron and hydrogen nucleus be q_1 and q_2. Then, Coulomb's force between them at a distance r is,

$$\mathbf{F} = -\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}$$

Putting, $\frac{1}{4\pi\varepsilon_0} = k$ (given)

$$\mathbf{F} = -k\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}$$

Since, the nucleus of hydrogen atom has one proton, so charge on nucleus is e i.e.

$q_2 = +e$

also $q_1 = e$ for electron

So, $\mathbf{F} = -k\frac{e.e}{r^2}\hat{\mathbf{r}} = -k\frac{e^2}{r^2}\hat{\mathbf{r}}$

but $\hat{\mathbf{r}} = \frac{\mathbf{r}}{|\mathbf{r}|} = \frac{\mathbf{r}}{r}$.

Hence, $\mathbf{F} = -k\frac{e^2}{r^2}.\frac{\mathbf{r}}{r}$

$= -k\frac{e^2}{r^3}.\mathbf{r}$

08 When air is replaced by a dielectric medium of constant K, the maximum force of attraction between two charges, separated by a distance **[CBSE AIPMT 1999]**

(a) decreases K times

(b) increases K times

(c) remains unchanged

(d) becomes $\frac{1}{K^2}$ times

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Ans. *(a)*

According to Coulomb's law, force between two charges is directly proportional to product of charges and inversely proportional to square of distance between them. Thus,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \quad ...(i)$$

where, $\frac{1}{4\pi\varepsilon_0}$ = proportionality constant.

If a dielectric medium of constant K is placed between them, then new force between them,

$$F_1 = \frac{1}{4\pi\varepsilon_0 K}\cdot\frac{q_1 q_2}{r^2} \quad ...(ii)$$

Dividing Eq. (ii) by Eq. (i), we have

$$\frac{F_1}{F} = \frac{1}{K}$$

or $$F' = \frac{F}{K}$$

Thus, new force decreases K times.

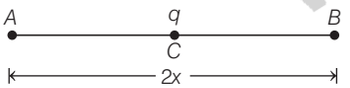
09 A charge q is placed at the centre of the line joining two exactly equal positive charges Q. The system of three charges will be in equilibrium, if q is equal to **[CBSE AIPMT 1995]**

(a) $-\frac{Q}{4}$ (b) $+Q$ (c) $-Q$ (d) $\frac{Q}{2}$

Ans. *(a)*

Let two equal charges Q each be held at A and B, where $AB = 2x$. C is the centre of AB, where charge q is held.

Net force on q is zero. So, q is already in equilibrium.



For the three charges to be in equilibrium, net force on each charge must be zero.

Now, total force on Q at B is

$$\frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{x^2} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q\,Q}{(2x)^2} = 0$$

or $$\frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{x^2} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q^2}{4x^2}$$

or $$q = -\frac{Q}{4}$$

10 A charge q is placed at the centre of the line joining two exactly equal positive charges Q. The system of three charges will be in equilibrium, if q is equal to **[CBSE AIPMT 1995]**

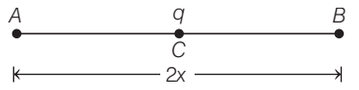
(a) $-\frac{Q}{4}$ (b) $+Q$

(c) $-Q$ (d) $\frac{Q}{2}$

Ans. *(a)*

Let two equal charges Q each be held at A and B, where $AB = 2x$. C is the centre of AB, where charge q is held.

Net force on q is zero. So, q is already in equilibrium.



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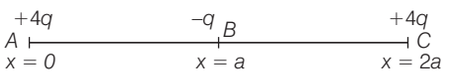
or $$q = -\frac{Q}{4}$$

11 Point charges $+4q, -q$ and $+4q$ are kept on the x-axis at points $x = 0, x = a$ and $x = 2a$, respectively. Then, **[CBSE AIPMT 1988]**

(a) only $-q$ is in stable equilibrium
(b) None of the charges is in equilibrium
(c) all the charges are in unstable equilibrium
(d) all the charges are in stable equilibrium

Ans. *(c)*

Net force on charge placed at A due to charges placed at C and B



$$F_A = \frac{1}{4\pi\varepsilon_0}\frac{(+4q)(-q)}{a^2} + \frac{1}{4\pi\varepsilon_0}\frac{(+4q)(+4q)}{(2a)^2}$$

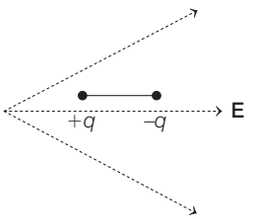
$$= -\frac{1}{4\pi\varepsilon_0}\frac{4q^2}{a^2} + \frac{1}{4\pi\varepsilon_0}\frac{4q^2}{a^2} = 0$$

Similarly, F_B and F_C will be zero.

As net force on each charge is zero, therefore all the charges are in equilibrium. If we were to displace $-q$ to the right, (in figure), net force of attraction will be to the right which will displace it further. Therefore, equilibrium is unstable.

TOPIC 2
Electric and Field Lines

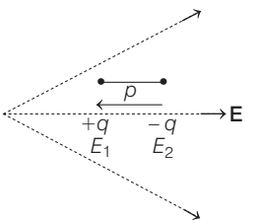
12 A dipole is placed in an electric field as shown. In which direction will it move? **[NEET 2021]**



(a) Towards the left as its potential energy will increase
(b) Towards the right as its potential energy will decrease
(c) Towards the left as its potential energy will decrease
(d) Towards the right as its potential energy will increase

Ans. *(b)*

We know that, the direction of electric dipole moment is from negative charge to positive charge.



The strength of the electric field at $+q$ is greater than that of $-q$ charge, i.e. $|E_1| > |E_2|$.

So, the net force on the dipole act towards the right side.

We know that, a system always moves to decrease in its potential energy.

So, the given dipole move towards right side as its potential energy will decreases.

13 A spherical conductor of radius 10 cm has a charge of 3.2×10^{-7} C distributed uniformly. What is the magnitude of electric field at a point 15 cm from the centre of the sphere? **[NEET (Sep.) 2020]**

$\left(\frac{1}{4\pi\varepsilon_0} = 9\times10^9\ \text{Nm}^2/\text{C}^2\right)$

(a) 1.28×10^5 N/C (b) 1.28×10^6 N/C
(c) 1.28×10^7 N/C (d) 1.28×10^4 N/C

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Ans. *(a)*

Given, radius, $r = 10\text{ cm} = 10 \times 10^{-2}$ m

Charge, $q = 3.2 \times 10^{-7}$ C

Electric field, $E = ?$

Electric field at a point ($x = 15$ cm) from the centre of the sphere is

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{x^2}$$

$$= 9 \times 10^9 \times \frac{3.2 \times 10^{-7}}{(15 \times 10^{-2})^2}$$

$$= 1.28 \times 10^5 \text{ N/C}$$

Hence, correct option is (a).

14 An electron falls from rest through a vertical distance h in a uniform and vertically upward directed electric field E. The direction of electric field is now reversed, keeping its magnitude the same. A proton is allowed to fall from rest in it through the same vertical distance h. The time of fall of the electron, in comparison to the time of fall of the proton is **[NEET 2018]**

(a) 10 times greater
(b) 5 times greater
(c) smaller
(d) equal

Ans. *(c)*

Force on a charged particle in the presence of an electric field is given as

$$F = qE \quad \ldots(i)$$

where, q is the charge on the charged particle and E is the electric field.

From Newton's second law of motion, force on a particle with mass m is given as

$$F = ma \quad \ldots(ii)$$

where, a is the acceleration.

From Eqs. (i) and (ii), we get

$$F = ma = qE$$

$$\Rightarrow \quad a = \frac{qE}{m} \quad \ldots(iii)$$

Now, consider that a particle falls from rest through a vertical distance h. Therefore, $u = 0$ and the second equation of motion becomes

$$s = ut + \frac{1}{2}at^2$$

or $$h = 0 \times t + \frac{1}{2}at^2$$

$$= \frac{1}{2} \times \frac{qE}{m} t^2 \quad [\text{from Eq. (iii)}]$$

$$\Rightarrow \quad t^2 = \frac{2hm}{qE}$$

or $$t = \sqrt{\frac{2hm}{qE}}$$

Since, the particles given in the question is electron and proton; and the quantity $\sqrt{\frac{2h}{qE}}$ (here, $q_p = q_e = e$) for both of them is constant. Thus, we can write

$$t = k\sqrt{m}$$

where, $$k = \sqrt{\frac{2h}{qE}}$$

or $$t \propto \sqrt{m}$$

As, mass of proton (m_p) >> mass of electron (m_e).

Thus, the time of fall of an electrons would be smaller than the time of fall of a protons.

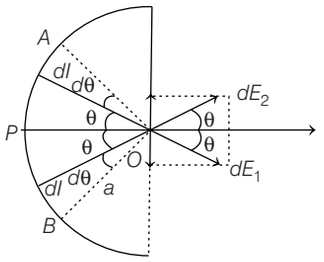
15 A charged wire is bent in the form of a semicircular arc of radius a. If charge per unit length is λ coulomb/metre, the electric field at the centre O is **[CBSE AIPMT 2000]**

(a) $\frac{\lambda}{2\pi a^2 \varepsilon_0}$ (b) $\frac{\lambda}{4\pi^2 \varepsilon_0 a}$

(c) $\frac{\lambda}{2\pi\varepsilon_0 a}$ (d) zero

Ans. *(c)*

Considering symmetric elements each of length dl at A and B, we know that electric fields perpendicular to PO are cancelled and those along PO are added. The electric field due to an element of length $dl\ (= a d\theta)$ along PO.



$$dE = \frac{1}{4\pi\varepsilon_0} \frac{d\theta}{a^2} \cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{\lambda dl}{a^2} \cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0} \frac{\lambda(a\, d\theta)}{a^2} \cos\theta \ (\because dl = a d\theta)$$

Net electric field at O

$$E = \int_{-\pi/2}^{\pi/2} dE = 2\int_0^{\pi/2} \frac{1}{4\pi\varepsilon_0} \frac{\lambda a \cos\theta\, d\theta}{a^2}$$

$$= 2 \cdot \frac{1}{4\pi\varepsilon_0} \frac{\lambda}{a} [\sin\theta]_0^{\pi/2}$$

$$= 2 \cdot \frac{1}{4\pi\varepsilon_0} \cdot \frac{\lambda}{a} \cdot 1 = \frac{\lambda}{2\pi\varepsilon_0 a}$$

16 A particle of mass m and charge q is placed at rest in a uniform electric field E and then released. The kinetic energy attained by the particle after moving a distance y is **[CBSE AIPMT 1998]**

(a) qEy^2 (b) qE^2y (c) qEy (d) q^2Ey

Ans. *(c)*

Electric force on charged particle is given by

$$F = qE$$

Kinetic energy attained by particle
= work done
= force × displacement
$= qE \times y$

Alternative

Force on charged particle in a uniform electric field is

$$F = ma = Eq$$

or $$a = \frac{Eq}{m} \quad \ldots(i)$$

From the equation of motion, we have

$$v^2 = u^2 + 2ay$$

$$= 0 + 2 \times \frac{Eq}{m} \times y \quad [u = 0]$$

$$= \frac{2Eqy}{m}$$

Now, kinetic energy of the particle

$$K = \frac{1}{2} mv^2$$

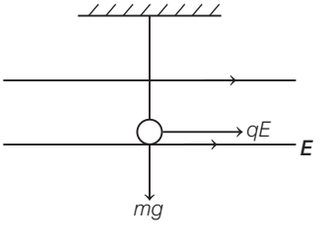
$$= \frac{m}{2} \times \frac{2Eqy}{m} = qEy$$

17 A pendulum bob of mass 30.7×10^{-6} kg and carrying a charge 2×10^{-8} C is at rest in a horizontal uniform electric field of 20000 V/m. The tension in the thread of the pendulum is ($g = 9.8\text{ m/s}^2$) **[CBSE AIPMT 1990]**

(a) 3×10^{4} N (b) 4×10^{-4} N
(c) 5×10^{-4} N (d) 6×10^{-4} N

Ans. *(c)*

There are 2 forces acting on pendulum (i) its weight



(i) Weight,

$$mg = 30.7 \times 10^{-6} \times 9.8$$

$$= 3 \times 10^{-4} \text{ N}$$

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vertically downward, and

(ii) Force, $F = qE$

$= 2 \times 10^{-8} \times 20000$

$= 4 \times 10^{-4}$ N

In the horizontal direction.

So, net tension, $T = \sqrt{(mg)^2 + F^2}$

$= \sqrt{(3 \times 10^{-4})^2 + (4 \times 10^{-4})^2}$

$= 5 \times 10^{-4}$ N

TOPIC 3
Electric Dipole

18 Polar molecules are the molecules **[NEET 2021]**

(a) having zero dipole moment
(b) acquire a dipole moment only in the presence of electric field due to displacement of charges.
(c) acquire a dipole moment only when magnetic field is absent
(d) having a permanent electric dipole moment

Ans. *(d)*

In polar molecules, the positive charge and negative charge do not overlap each other. So, the total charge on the polar molecule is zero. Thus, these types of molecules have permanent electric dipole moment. e.g. Water is polar molecule.

19 The electric field at a point on the equatorial plane at a distance r from the centre of a dipole having dipole moment $\vec{P}$ is given by ($r >>$ separation of two charges forming the dipole, ε_0 = permittivity of free space) **[NEET (Oct.) 2020]**

(a) $E = \frac{P}{4\pi\varepsilon_0 r^3}$ (b) $E = \frac{2P}{4\pi\varepsilon_0 r^3}$

(c) $E = -\frac{P}{4\pi\varepsilon_0 r^2}$ (d) $E = -\frac{P}{4\pi\varepsilon_0 r^3}$

Ans. *(a)*

Electric field due to electric dipole on equatorial plane at a distance r from the centre of dipole is given as

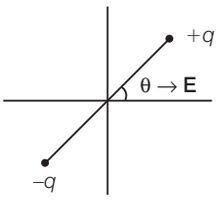
$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^3}$$

20 An electric dipole of moment p is placed in an electric field of intensity E. The dipole acquires a position such that the axis of the dipole makes an angle θ with the direction of the field. Assuming that the potential energy of the dipole to be zero when $\theta = 90°$, the torque and the potential energy of the dipole will respectively be **[CBSE AIPMT 2012]**

(a) $pE\sin\theta, -pE\cos\theta$
(b) $pE\sin\theta, -2pE\cos\theta$
(c) $pE\sin\theta, 2pE\cos\theta$
(d) $pE\cos\theta, -pE\sin\theta$

Ans. *(a)*

Here, torque, $\tau = pE\sin\theta$



Potential energy of the dipole,

$$U = \int_0^{\theta} \tau d\theta = \int_{\pi/2}^{\theta} pE\sin\theta d\theta = -pE[\cos\theta]_{\pi/2}^{\theta}$$

$$= -pE\cos\theta$$

21 An electric dipole is placed at an angle of 30° with an electric field intensity 2×10^5 N/C. It experiences a torque equal to 4 Nm. The charge on the dipole, if the dipole length is 2 cm, is **[NEET 2016]**

(a) 8 mC (b) 2 mC (c) 5 mC (d) 7 μC

Ans. *(b)*

$\because$ Torque on an electric dipole in an electric field,

$$\tau = \mathbf{p} \times \mathbf{E} \Rightarrow |\tau| = pE\sin\theta$$

where, θ is angle between E and p

$\Rightarrow \quad 4 = p \times 2 \times 10^5 \times \sin 30$

$\Rightarrow \quad p = 4 \times 10^{-5}$ cm

$\Rightarrow \quad p = q2l$

$\therefore \quad q2l = 4 \times 10^{-5}$

where, $2l = 2\,\text{cm} = 2 \times 10^{-4}$ m

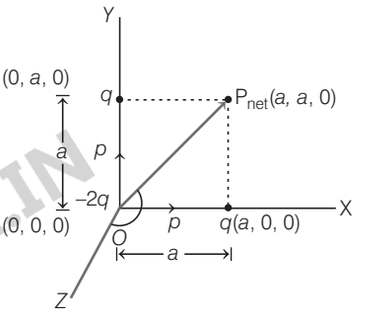
$\therefore \quad q = \frac{4 \times 10^{-5}}{2 \times 10^{-2}} \Rightarrow 2 \times 10^{-3}\,\text{C} = 2\,\text{mC}$

22 Three point charges $+q$, $-2q$ and $+q$ are placed at points $(x = 0, y = a, z = 0)$, $(x = 0, y = 0, z = 0)$ and $(x = a, y = 0, z = 0)$, respectively. The magnitude and direction of the electric dipole moment vector of this charge assembly are **[CBSE AIPMT 2007]**

(a) $\sqrt{2}\,qa$ along $+y$ direction
(b) $\sqrt{2}\,aq$ along the line joining points $(x = 0, y = 0, z = 0)$ and $(x = a, y = a, z = 0)$
(c) qa along the line joining points $(x = 0, y = 0, z = 0)$ and $(x = a, y = a, z = 0)$
(d) $\sqrt{2}\,aq$ along $+x$ direction

Ans. *(b)*

Choose the three coordinate axes as X, Y and Z and plot the charges with the given coordinates as shown. O is the origin at which $-2q$ charge is placed. The system is equivalent to two dipoles along x and y-directions respectively. The dipole moments of two dipoles are shown in figure.



The resultant dipole moment will be directed along OP where coordinate of $\mathbf{p}_{net}$ is given by $(a, a, 0)$. The magnitude of resultant dipole moment is

$$\mathbf{p}_{net} = \sqrt{p^2 + p^2}$$

$$= \sqrt{(qa)^2 + (qa)^2} = \sqrt{2}\,qa$$

23 An electric dipole of moment $\mathbf{p}$ is lying along a uniform electric field $\mathbf{E}$. The work done in rotating the dipole by 90° is **[CBSE AIPMT 2006]**

(a) $\sqrt{2}\,pE$ (b) $\frac{pE}{2}$

(c) $2pE$ (d) pE

Ans. *(d)*

When an electric dipole is placed in an electric field $\mathbf{E}$, a torque $\tau = \mathbf{p} \times \mathbf{E}$ acts on it. This torque tries to rotate the dipole.

If the dipole is rotated from an angle θ_1 to θ_2, then work done by external force is given by

$$W = pE(\cos\theta_1 - \cos\theta_2) \quad \ldots(i)$$

Putting $\theta_1 = 0°, \theta_2 = 90°$ in the Eq. (i), we get

$$W = pE(\cos 0° - \cos 90°)$$

$$= pE(1 - 0) = pE$$

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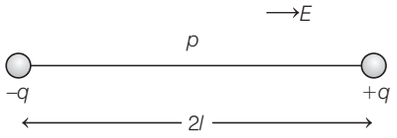
24 An electric dipole has the magnitude of its charge as q and its dipole moment is p. It is placed in a uniform electric field E. If its dipole moment is along the direction of the field, the force on it and its potential energy are respectively
[CBSE AIPMT 2004]

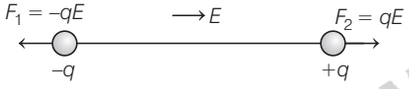
(a) $2qE$ and minimum
(b) qE and pE
(c) zero and minimum
(d) qE and maximum

Ans. *(c)*

An electric dipole is an arrangement of two equal and opposite charges placed at a distance $2l$. The dipole is placed in electric field as such its dipole moment is in direction of electric field as shown in figure. Direction of dipole moment is from negative to positive charge.



Now, force on the charge q is $F_2 = qE$ along the direction of E and force on charge $-q$ is
$F_1 = -qE$ in the direction opposite to E.
Since, forces on the dipole are equal and opposite, so net force on the electric dipole is zero.



Now, potential energy of the dipole.

$$U = -pE\cos\theta$$

where, θ is the angle between direction of electric field and direction of dipole moment.

$\therefore \quad \theta = 0°$

Hence, $U = -pE\cos 0° = -pE$ (minimum)

25 A point Q lies on the perpendicular bisector of an electric dipole of dipole moment p. If the distance of Q from the dipole is r, (much larger than the size of the dipole) then electric field at Q is proportional to
[CBSE AIPMT 1998]

(a) p^{-1} and r^2 (b) p and r^{-2}
(c) p^2 and r^{-3} (d) p and r^{-3}

Ans. *(d)*

Electric field due to a dipole at bisector or at a point on its broad side on position or equatorial position is given by

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^3} \text{ or } E \propto \frac{p}{r^3} \qquad ...(i)$$

where, r is the distance of that point from centre of dipole and p is dipole moment.
So, from Eq. (i)

$$E \propto p \text{ and } E \propto r^{-3}$$

26 The formation of a dipole is due to two equal and dissimilar point charges placed at a
[CBSE AIPMT 1996]

(a) short distance
(b) long distance
(c) above each other
(d) None of these

Ans. *(a)*

An electric dipole consists of a pair of equal and opposite point charges separated by a very small distance. Atoms or molecules of ammonia, water, alcohol, carbon dioxide, HCl etc are some of the examples of electric dipoles, because in these cases, the centres of positive and negative charge distributions are separated by some small distance.

27 Intensity of an electric field (E) depends on distance r due to a dipole, is related as
[CBSE AIPMT 1996]

(a) $E \propto \frac{1}{r}$ (b) $E \propto \frac{1}{r^2}$ (c) $E \propto \frac{1}{r^3}$ (d) $E \propto \frac{1}{r^4}$

Ans. *(c)*

Field intensity on axial line of electric dipole is given by

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{r^3} \qquad ...(i)$$

and electric field at equatorial position is given by

$$E = \frac{1}{4\pi\varepsilon_0}\times\frac{p}{r^3} \qquad ...(ii)$$

where, p is electric dipole moment.
From Eqs. (i) and (ii), we get

$$E \propto \frac{1}{r^3}$$

28 An electric dipole, consisting of two opposite charges of 2×10^{-6} C each separated by a distance 3 cm is placed in an electric field of 2×10^5 N/C. Torque on the dipole is
[CBSE AIPMT 1995]

(a) 12×10^{-1} N-m (b) 12×10^{-2} N-m
(c) 12×10^{-3} N-m (d) 12×10^{-4} N-m

Ans. *(c)*

When a dipole of dipole moment $\mathbf{p}$ is placed in a uniform external electric field $\mathbf{E}$, then torque acting on dipole is

$$\tau = \mathbf{p}\times\mathbf{E} = |p|\times|E|\sin\theta$$

where, $\mathbf{p} = q\times 2\mathbf{l}$ ($2l$ is length of dipole)
Given, $q = 2\times10^{-6}$C
$2l = 3$ cm $= 3\times10^{-2}$ m
$E = 2\times10^5$ N/C
As, $\tau = pE\sin\theta \qquad (\theta = 90°\ p \perp \mathbf{E})$
So, $\tau = pE$
$\therefore \quad \tau = (2\times10^{-6})\times(3\times10^{-2})\times(2\times10^5)$
$= 12\times10^{-3}$ N-m

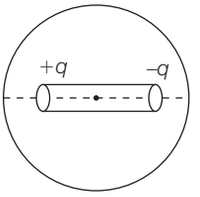
TOPIC 4
Electric Flux and Gauss's Laws

29 A sphere encloses an electric dipole with charge $\pm3\times10^{-6}$ C. What is the total electric flux across the sphere?
[NEET (Odisha) 2019]

(a) -3×10^{-6} N-m^2/C
(b) zero
(c) 3×10^6 N-m^2/C
(d) 6×10^{-6} N-m^2/C

Ans. *(b)*

When a sphere encloses a charged dipole,



Here, $q = \pm3\times10^{-6}$ C
Thus, according to Gauss's law, the net electric flux across the closed surface is equal to the net charge enclosed by it divided by ε_0, i.e.

$$\phi_E = \frac{q_{in}}{\varepsilon_0} = \frac{+3\times10^{-6} - 3\times10^{-6}}{\varepsilon_0} = 0$$

Hence, electric flux across the sphere is zero.

30 Two parallel infinite line charges with linear charge densities $+\lambda$ C/m and $-\lambda$ C/m are placed at a distance of $2R$ in free space. What is the electric field mid-way between the two line charges?
[NEET (National) 2019]

(a) $\frac{2\lambda}{\pi\varepsilon_0 R}$ N/C (b) $\frac{\lambda}{\pi\varepsilon_0 R}$ N/C
(c) $\frac{\lambda}{2\pi\varepsilon_0 R}$ N/C (d) Zero

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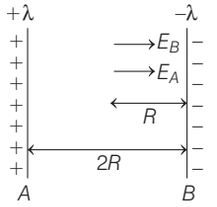
Ans. *(b)*

Consider two infinite line charges with linear charge densities + λ C/m and – λ C/m respectively, which are lying in *y*-direction as shown in the figure below.



Then, the electric field due to line *A* at the mid way between the two line charges, i.e. at *R* is

$$|\mathbf{E}_A| = \frac{\lambda}{2\pi\varepsilon_0 R}\ \text{N/C} \qquad \ldots(i)$$

which lies along +ve *x*-axis (outward), i.e. from *A* to *B*.

Similarly, the electric field due to line *B* at the mid-way between the two line charges, i.e. at *R* is

$$|\mathbf{E}_B| = \frac{\lambda}{2\pi\varepsilon_0 R}\ \text{N/C} \qquad \ldots(ii)$$

Due to negative charge on *B*, $\mathbf{E}_B$ also lies along +ve *x*-axis (inward), i.e. from *A* to *B*.

So, the resultant electric field at *R* is given as

$$|\mathbf{E}_R| = |\mathbf{E}_A| + |\mathbf{E}_B|$$

Substituting the values from Eqs. (i) and (ii), we get

$$|\mathbf{E}_R| = \frac{\lambda}{2\pi\varepsilon_0 R} + \frac{\lambda}{2\pi\varepsilon_0 R} = \frac{\lambda}{\pi\varepsilon_0 R}\ \text{N/C}$$

Which also lies along the + ve *x*-axis, i.e. from *A* to *B*.

31 A hollow metal sphere of radius *R* is uniformly charged. The electric field due to the sphere at a distance *r* from the centre **[NEET (National) 2019]**

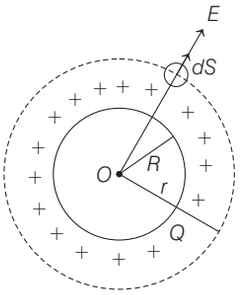
(a) zero as *r* increases for $r < R$, decreases as *r* increases for $r > R$
(b) zero as *r* increases for $r < R$, increases as *r* increases for $r > R$
(c) decreases as *r* increases for $r < R$ and for $r > R$
(d) increases as *r* increases for $r < R$ and for $r > R$

Ans. *(a)*

As the hollow sphere is uniformly charged, so the net charge will appear on the surface of the sphere.

(i) The electric field at a point outside the hollow sphere is

$$\phi = \oint_S \mathbf{E}\cdot d\mathbf{S} = \frac{Q_{\text{enclosed}}}{\varepsilon_0} \qquad [\text{from Gauss' law}]$$



$$\Rightarrow \quad E(4\pi r^2) = \frac{Q}{\varepsilon_0} \Rightarrow E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$\Rightarrow \quad E \propto \frac{1}{r^2}$$

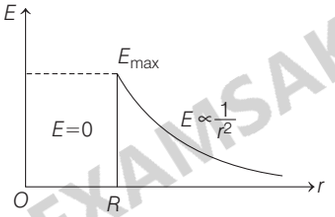
(ii) The electric field at the surface ($r = R$),

$$E = \frac{Q}{4\pi\varepsilon_0 R}$$

(iii) The electric field inside hollow sphere is

$$E = \frac{Q}{4\pi\varepsilon_0 r} = 0 \qquad [\because Q_{\text{inside}} = 0]$$

Thus, the electric field is zero inside the hollow sphere maximum at the surface and decreases as *r* increases for $r > R$. This can be shown graphically as



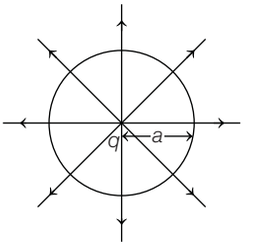
32 The electric field in a certain region is acting radially outward and is given by $E = Ar$. A charge contained in a sphere of radius '*a*' centred at the origin of the field' will be given by **[CBSE AIPMT 2015]**

(a) $4\pi\varepsilon_0 A a^2$ (b) $A\varepsilon_0 a^2$
(c) $4\pi\varepsilon_0 A a^3$ (d) $\varepsilon_0 A a^3$

Ans. *(c)*

Given,

$$E = Ar \qquad \ldots(i)$$



Here, $r = a \Rightarrow E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2}$

From Eq. (i),

$$\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{a^2} = Aa \Rightarrow q = 4\pi\varepsilon_0 A a^3$$

33 What is the flux through a cube of side *a* if a point charge of *q* is at one of its corner? **[CBSE AIPMT 2012]**

(a) $\frac{2q}{\varepsilon_0}$ (b) $\frac{q}{8\varepsilon_0}$ (c) $\frac{q}{\varepsilon_0}$ (d) $\frac{q}{2\varepsilon_0}6a^2$

Ans. *(b)*

Concept According to Gauss's law, the electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

As the charge enclosed = *q*/8

So, electric flux $= \frac{q_{\text{enclosed}}}{\varepsilon_0} \Rightarrow \phi = \frac{q}{8\varepsilon_0}$

34 A charge *Q* is enclosed by a Gaussian spherical surface of radius *R*. If the radius is doubled, then the outward electric flux will **[CBSE AIPMT 2011]**

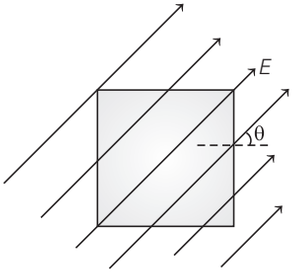
(a) be reduced to half
(b) remain the same
(c) be doubled
(d) increase four times

Ans. *(b)*

Total flux through any enclosed surface is given by, $\phi_{\text{net}} = \frac{\text{net charge enclosed}}{\varepsilon_0}$

Hence, we can say that the electric flux depends only on net enclosed charge by surface.

35 A square surface of side *L* metre in the plane of the paper is placed in a uniform electric field *E* (V/m) acting along the same place at an angle θ with the horizontal side of the square as shown in figure. The electric flux linked to the surface in unit of V-m, is **[CBSE AIPMT 2010]**



(a) EL^2 (b) $EL^2\cos\theta$
(c) $EL^2\sin\theta$ (d) 0

Ans. *(d)*

Flux of electric field **E** through any area **A** is defined as $\phi = E\cdot A\cos\theta$ or $\phi = \mathbf{E}\cdot\mathbf{A} = 0$, the lines are parallel to the surface.

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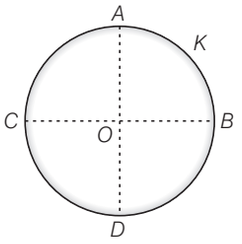
36



A thin conducting ring of radius R is given a charge $+Q$. The electric field at the centre O of the ring due to the charge on the part AKB of the ring is E. The electric field at the centre due to the charge on the part $ACDB$ of the ring is **[CBSE AIPMT 2008]**

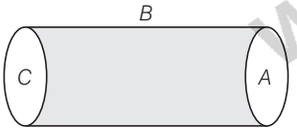
(a) $3E$ along KO (b) E along OK
(c) E along KO (d) $3E$ along OK

Ans. *(b)*

Concept Net electric field at the centre of thin conducting ring is zero.

$$\mathbf{E}_{total} = 0$$
$$\mathbf{E}_{AKB} + \mathbf{E}_{ACDB} = 0$$
$$\mathbf{E}_{ACDB} = -\mathbf{E}_{AKB}$$
$$\mathbf{E}_{ACDB} = E \text{ along } OK$$

37 A hollow cylinder has a charge q coulomb within it. If ϕ is the electric flux in unit of voltmeter associated with the curved surface B, the flux linked with the plane surface A in unit of voltmeter will be **[CBSE AIPMT 2007]**



(a) $\frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi\right)$ (b) $\frac{q}{2\varepsilon_0}$
(c) $\frac{\phi}{3}$ (d) $\frac{q}{\varepsilon_0} - \phi$

Ans. *(a)*

Gauss's law states that the net electric flux through any closed surface is equal to the net charge inside the surface divided by ε_0.

i.e. $$\phi_{total} = \frac{q_{inside}}{\varepsilon_0}$$

Let electric flux linked with surfaces A, B and C are ϕ_A, ϕ_B and ϕ_C respectively, i.e.

$$\phi_{total} = \phi_A + \phi_B + \phi_C$$

Since, $\phi_C = \phi_A$

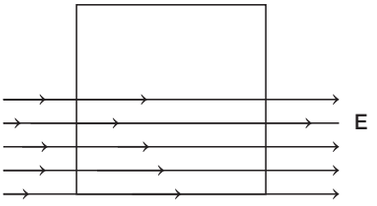
$$\therefore \quad 2\phi_A + \phi_B = \phi_{total} = \frac{q}{\varepsilon_0}$$

or $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi_B\right)$$

But $\phi_B = \phi$ (given)

Hence, $$\phi_A = \frac{1}{2}\left(\frac{q}{\varepsilon_0} - \phi\right)$$

38 A square surface of side L metre is in the plane of the paper. A uniform electric field $\mathbf{E}$ (V/m), also in the plane of the paper, is limited only to the lower half of the square surface, (see figure). The electric flux in SI units associated with the surface is **[CBSE AIPMT 2006]**



(a) $\frac{EL^2}{(2\varepsilon_0)}$ (b) $\frac{EL^2}{2}$
(c) zero (d) EL^2

Ans. *(c)*

As we know, the electric flux (ϕ) through any surface area is given by,

$$\phi = \mathbf{E}\cdot\mathbf{ds} = |E||ds|\cos\theta$$

As according to question, surface area is in plane of paper and $\mathbf{E}$ is also in plane of paper. So, angle between area vector and $\mathbf{E}$ is 90°

So, $\phi = |E||ds|\cos 90° = 0°$

39 A charge q is located at the centre of a cube. The electric flux through any face is **[CBSE AIPMT 2003]**

(a) $\frac{\pi q}{6(4\pi\varepsilon_0)}$ (b) $\frac{q}{6(4\pi\varepsilon_0)}$
(c) $\frac{2\pi q}{6(4\pi\varepsilon_0)}$ (d) $\frac{4\pi q}{6(4\pi\varepsilon_0)}$

Ans. *(d)*

As we know expression of Gauss's law is

$$\oint \mathbf{E}\cdot\mathbf{ds} = \frac{q_{inside}}{\varepsilon_0}$$

So, $$\phi = \frac{q}{\varepsilon_0} \quad [\phi = \oint \mathbf{E}\cdot\mathbf{ds}]$$

This is the net flux coming out from cube.

Since, a cube has 6 sides so electric flux through any face is $\phi' = \frac{\phi}{6} = \frac{q}{6\varepsilon_0}$

40 A charge $q\,\mu$C is placed at the centre of a cube of a side 0.1 m, then the electric flux diverging from each face of the cube is **[CBSE AIPMT 2001]**

(a) $\frac{q\times10^{-6}}{24\varepsilon_0}$ (b) $\frac{q\times10^{-4}}{\varepsilon_0}$
(c) $\frac{q\times10^{-6}}{6\varepsilon_0}$ (d) $\frac{q\times10^{-4}}{12\varepsilon_0}$

Ans. *(c)*

The electric flux emerging from the cube is

$$\phi = \frac{1}{\varepsilon_0} \times \text{charge enclosed} \qquad (q_{inside})$$
$$= \frac{1}{\varepsilon_0} \times q_{inside} \times 10^{-6}$$
$$= \frac{1}{\varepsilon_0} \times q_{inside} \times 10^{-6} \quad [q_{inside} = q \times 10^{-6}]$$

Since, a cube has six faces, so electric flux through each face is,

$$\phi' = \frac{\phi}{6} = \frac{1}{6\varepsilon_0} \times q \times 10^{-6} = \frac{q\times10^{-6}}{6\varepsilon_0}$$

41 A charge q is placed at the corner of a cube of side a. The electric flux through the cube is **[CBSE AIPMT 2000]**

(a) $\frac{q}{\varepsilon_0}$ (b) $\frac{q}{3\varepsilon_0}$ (c) $\frac{q}{6\varepsilon_0}$ (d) $\frac{q}{8\varepsilon_0}$

Ans. *(d)*

According to Gauss's law, the electric flux through a closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

Since, q is the charge enclosed by the surface, then electric flux, $\phi = \frac{q}{\varepsilon_0}$

If charge q is placed at a corner of cube, it will be divided into 8 such cubes.

Therefore, electric flux through the cube is

$$\phi' = \frac{1}{8}\left(\frac{q}{\varepsilon_0}\right)$$

42 A hollow insulated conducting sphere is given a positive charge of 10 μC. What will be the electric field at the centre of the sphere if its radius is 2 m? **[CBSE AIPMT 1998]**

(a) Zero (b) 5 μCm^{-2}
(c) 20 μCm^{-2} (d) 8 μCm^{-2}

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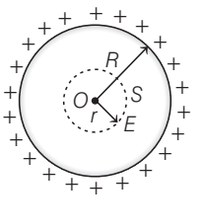
Ans. *(a)*

Charge resides on the outer surface of a conducting hollow or solid sphere of radius R (say). We consider a spherical surface of radius $r < R$.



By Gauss' theorem,

$$\sum \mathbf{E}\cdot\mathbf{ds} = \frac{q_{inside}}{\varepsilon_0}$$

or $E \times 4\pi r^2 = \frac{1}{\varepsilon_0} \times q_{inside}$

and we know that $q_{inside} = 0$

So, $E = 0$

i.e. electric field inside a hollow sphere is zero.

43 A point charge $+q$ is placed at mid-point of a cube of side L. The electric flux emerging from the cube is **[CBSE AIPMT 1996]**

(a) $\frac{q}{\varepsilon_0}$ (b) $\frac{6qL^2}{\varepsilon_0}$ (c) $\frac{q}{6L^2\varepsilon_0}$ (d) zero

Ans. *(a)*

By Gauss's theorem, total electric flux over the closed surface is $\frac{1}{\varepsilon_0}$ times the total charges contained inside surface.

$\therefore$ Total electric flux

$$= \frac{\text{total charge inside cube}}{\varepsilon_0}$$

or $\phi = \frac{q}{\varepsilon_0}$

44 The electric field strength in air at NTP is 3×10^6 V / m. The maximum charge that can be given to a spherical conductor of radius 3 m is **[CBSE AIPMT 1993]**

(a) 3×10^4 C (b) 3×10^{-3} C
(c) 3×10^{-2} C (d) 3×10^{-1} C

Ans. *(b)*

Given, $E_{max} = 3 \times 10^6$ V/m and $R = 3$ m

We know that,

$$E = \frac{1}{4\pi\varepsilon_0} \times \frac{Q}{R^2} \Rightarrow$$

$$Q_{max} = 4\pi\varepsilon_0 R^2 E_{max} = \frac{3\times3\times3\times10^6}{9\times10^9}$$

$= 3 \times 10^{-3}$ C

45 Two spherical conductors A and B of radii 1 mm and 2 mm are separated by a distance of 5 cm and are uniformly charged. If the spheres are connected by a conducting wire then in equilibrium condition, the ratio of the magnitude of the electric fields at the surfaces of spheres A and B is **[CBSE AIPMT 1992]**

(a) 4 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 4

Ans. *(a)*

Concept The electric field at any point, outside or inside, the conducting sphere can depend only on r (the radial distance from the centre of the sphere to the point).

When the two conducting spheres are connected by a conducting wire, charge will flow from one sphere (having higher potential) to other (having lower potential) till both acquire the same potential.

As, $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$

So, for different cases, $\frac{E_1}{E_2} = \left(\frac{r_2}{r_1}\right)^2 = 4:1$

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16

Electrostatic Potential and Capacitance

TOPIC 1
Electrostatic Potential and Potential Energy

01 Twenty seven drops of same size are charged at 220 V each. They combine to form a bigger drop. Calculate the potential of the bigger drop. **[NEET 2021]**

(a) 660 V (b) 1320 V
(c) 1520 V (d) 1980 V

Ans. *(d)*

Given, the number of small drops, $n = 27$

Potential on each charged drop, $V = 220$ V

Consider r be the radius of the small drops and R be the radius of the bigger drop.

According to the question, 27 small drops of same size combine to form a bigger drop. So, the volume remains same, i.e.

$$V_{bigger} = 27 \times V_{small}$$

$$\Rightarrow \frac{4}{3}\pi R^3 = 27 \times \frac{4}{3}\pi r^3$$

$$\Rightarrow \quad R^3 = 27 \times r^3 \;\Rightarrow\; R = 3r$$

Now, the potential of the small drop,

$$V = \frac{Kq}{r} \qquad \ldots(i)$$

Here, q is the charge on the small drop.

The potential of the bigger drop,

$$V' = \frac{KQ}{R}$$

Here, Q is the charge on the bigger drop.

The charge on the bigger drop is 27 times the charge on the smaller drop, i.e. $Q = 27q$

So, the potential of the bigger drop,

$$V' = \frac{K \times 27q}{3r} \;\Rightarrow\; V' = 9\frac{Kq}{r}$$

$$V' = 9V \qquad [\text{from Eq. (i)}]$$

$$= 9 \times 220 = 1980 \text{ V}$$

02 Two charged spherical conductors of radii R_1 and R_2 are connected by a wire. Then, the ratio of surface charge densities of the spheres (σ_1 / σ_2) is **[NEET 2021]**

(a) $\frac{R_1}{R_2}$ (b) $\frac{R_2}{R_1}$

(c) $\sqrt{\left(\frac{R_1}{R_2}\right)}$ (d) $\frac{R_1^2}{R_2^2}$

Ans. *(b)*

When two charged spherical conductors are connected by a conducting wire, then the potential becomes same in both the spherical conductor, i.e. $V_1 = V_2$

$$\Rightarrow \frac{Kq_1}{R_1} = \frac{Kq_2}{R_2} \;\Rightarrow\; \frac{q_1}{q_2} = \frac{R_1}{R_2} \qquad \ldots(i)$$

As we know that, the surface charge density of the charged spherical conductor,

$$\sigma = \frac{q}{4\pi R^2}$$

where, q is the charge on the spherical conductor,

r is the radius of the spherical conductor.

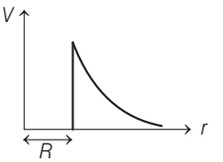
$$\therefore \qquad \frac{\sigma_1}{\sigma_2} = \frac{\frac{q_1}{4\pi R_1^2}}{\frac{q_2}{4\pi R_2^2}}$$

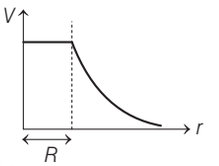
$$\Rightarrow \qquad \frac{\sigma_1}{\sigma_2} = \frac{q_1}{q_2}\frac{R_2^2}{R_1^2}$$

$$\Rightarrow \qquad \frac{\sigma_1}{\sigma_2} = \frac{R_1}{R_2}\frac{R_2^2}{R_1^2} \qquad [\text{from Eq. (i)}]$$

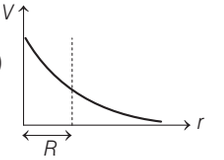
$$\Rightarrow \qquad \frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$$

03 The variation of electrostatic potential with radial distance r from the centre of a positively charged metallic thin shell of radius R is given by the graph **[NEET (Oct.) 2020]**

(a)


(b)


(c)

(d)


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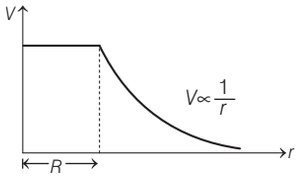
Ans. *(b)*

Since, electric potential remains constant inside the metallic spherical shell and same as the surface of spherical shell.

Outside the spherical shell, $V \propto \frac{1}{r}$

Hence, variation of potential (V) with distance r is given as



04 In a certain region of space with volume $0.2\,m^3$, the electric potential is found to be 5 V throughout. The magnitude of electric field in this region is **[NEET (Sep.) 2020]**

(a) 0.5 N/C (b) 1 N/C
(c) 5 N/C (d) zero

Ans. *(d)*

Given, volume, $V = 0.2 m^3$

Electric potential = 5 V = constant

Electric field = ?

We know that, for constant electric potential the value of electric field is zero.

i.e., $E = \frac{-dV}{dr} = \frac{-d(5)}{dr} = 0$

Hence, correct option is (d).

05 A short electric dipole has a dipole moment of 16×10^{-9} C-m. The electric potential due to the dipole at a point at a distance of 0.6 m from the centre of the dipole, situated on a line making an angle of 60° with the dipole axis is $\left(\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2\right)$ **[NEET (Sep.) 2020]**

(a) 200 V (b) 400 V (c) zero (d) 50 V

Ans. *(a)*

Given, electric dipole moment, $p = 16 \times 10^{-9}$ C-m

Distance, $r = 0.6$ m

Angle, $\theta = 60° \Rightarrow \cos 60° = \frac{1}{2}$

Electric potential at a point which is at a distance r at some angle θ from electric dipole is

$$V = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2} = \frac{9 \times 10^9 \times 16 \times 10^{-9} \times \frac{1}{2}}{(0.6)^2}$$

$$= 2 \times 10^2 = 200 \text{ V}$$

Hence, correct option is (a).

06 Two metal spheres, one of radius R and the other of radius $2R$ respectively have the same surface charge density σ. They are brought in contact and separated. What will be the new surface charge densities on them? **[NEET (Odisha) 2019]**

(a) $\sigma_1 = \frac{5}{6}\sigma, \quad \sigma_2 = \frac{5}{2}\sigma$

(b) $\sigma_1 = \frac{5}{2}\sigma, \quad \sigma_2 = \frac{5}{6}\sigma$

(c) $\sigma_1 = \frac{5}{2}\sigma, \quad \sigma_2 = \frac{5}{3}\sigma$

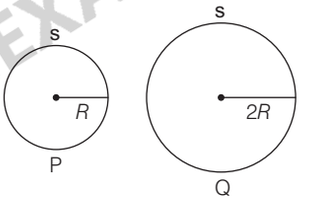
(d) $\sigma_1 = \frac{5}{3}\sigma, \quad \sigma_2 = \frac{5}{6}\sigma$

Ans. *(d)*

The surface charge density of a closed surface area having charge Q is given by

$$\sigma = \frac{\text{Charge}}{\text{Area}} = \frac{Q}{A} \quad \text{or} \quad Q = \sigma A$$

Thus, the charges on sphere P and Q having same charge density as shown in the figure below is given by



$$Q_P = \sigma \times 4\pi R^2 = 4\pi\sigma R^2 \quad \text{...(i)}$$

and $Q_Q = \sigma \times 4\pi(2R)^2 = 16\pi\sigma R^2 \quad \text{...(ii)}$

when they are brought in contact with each other, the total charge will be

$$Q_t = Q_P + Q_Q$$

$$= 4\pi\sigma R^2 + 16\pi\sigma R^2$$

[From Eq. (i) and (ii)]

$$= 20\pi\sigma R^2 \quad \text{...(iii)}$$

In connection of two charged conducting bodies, the potential will become same on both, i.e.

$$\frac{Q_P}{4\pi\epsilon_0 R} = \frac{Q_Q}{4\pi\epsilon_0 2R}$$

$$\Rightarrow \frac{Q_P}{R} = \frac{Q_Q}{2R} \Rightarrow \frac{Q_P}{Q_Q} = \frac{1}{2}$$

So, the charges on the sphere P and Q after separation will be distributed as

$$\Rightarrow Q_P' = \frac{1}{3}Q_t \text{ and } Q_Q' = \frac{2}{3}Q_t$$

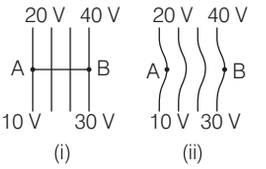
After separation, the new surface charge densities on P and Q will be

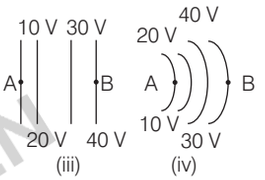
$$\sigma_P = \frac{Q_P'}{\text{Area}} = \frac{1}{3}\frac{Q_t}{\text{Area}} = \frac{1}{3}\frac{20\pi\sigma R^2}{4\pi R^2} = \frac{5}{3}\sigma$$

and $\sigma_Q = \frac{Q_Q'}{\text{Area}} = \frac{2}{3}\frac{Q_t}{\text{Area}} = \frac{2}{3} \times \frac{20\pi\sigma R^2}{4\pi(2R)^2}$

$$= \frac{2}{3} \times \frac{5}{4}\sigma = \frac{5}{6}\sigma$$

07 The diagrams below show regions of equipotentials.





A positive charge is moved from A to B in each diagram. **[NEET 2017]**

(a) Maximum work is required to move q in figure (iii)
(b) In all the four cases, the work done is the same
(c) Minimum work is required to move q in figure (i)
(d) Maximum work is required to move q in figure (ii)

Ans. *(b)*

We know that,

Work done (W) = $q\,\Delta V$

ΔV is same in all the cases. So, work done will be same in the all cases.

08 If potential (in volts) in a region is expressed as $V(x, y, z) = 6xy - y + 2yz$, the electric field (in N/C) at point (1, 1, 0) is **[CBSE AIPMT 2015]**

(a) $-(3\hat{\mathbf{i}} + 5\hat{\mathbf{j}} + 3\hat{\mathbf{k}})$ (b) $-(6\hat{\mathbf{i}} + 5\hat{\mathbf{j}} + 2\hat{\mathbf{k}})$
(c) $-(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + \hat{\mathbf{k}})$ (d) $-(6\hat{\mathbf{i}} + 9\hat{\mathbf{j}} + \hat{\mathbf{k}})$

Ans. *(b)*

Given, potential in a region, $V = 6xy - y + 2yz$.

Electric field in a region,

$$E = -\frac{\partial V}{\partial x}\hat{\mathbf{i}} - \frac{\partial V}{\partial y}\hat{\mathbf{j}} - \frac{\partial V}{\partial z}\hat{\mathbf{k}}$$

$$\Rightarrow \quad E = -6y\hat{\mathbf{i}} - (6x - 1)\hat{\mathbf{j}} - 2y\hat{\mathbf{k}}$$

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At, (1, 1, 0), electric field can be expressed,

$E = -(6\times 1\hat{\mathbf{i}}) - (6\times 1 - 1)\hat{\mathbf{j}} - 2\times 1.\hat{\mathbf{k}}$

$= -(6\hat{\mathbf{i}} + 5\hat{\mathbf{j}} + 2\hat{\mathbf{k}})$ N / C

09 A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are **[CBSE AIPMT 2014]**

(a) zero and $\frac{Q}{4\pi\varepsilon_0 R^2}$

(b) $\frac{Q}{4\pi\varepsilon_0 R}$ and zero

(c) $\frac{Q}{4\pi\varepsilon_0 R}$ and $\frac{Q}{4\pi\varepsilon_0 R^2}$

(d) Both are zero

Ans. *(b)*

In a conducting sphere charge is present on the surface of the sphere. So, electric field inside will be zero and potential remains constant from centre to surface of sphere and is equal to $\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

10 In a region, the potential is represented by $V(x, y, z) = 6x - 8xy - 8y + 6yz$, where V is in volts and x, y, z are in metres. The electric force experienced by a charge of 2 C situated at point (1, 1, 1) is **[CBSE AIPMT 2014]**

(a) $6\sqrt{5}$ N (b) 30 N

(c) 24 N (d) $4\sqrt{35}$ N

Ans. *(d)*

As we know that relation between potential difference and electric field $\mathbf{E}$ in a particular region is given by,

$\mathbf{E} = -\frac{dV}{dr}$

As $V = 6x - 8xy - 8y + 6yz$

So, $\mathbf{E} = -\frac{dV}{dr}$

$= -[(6 - 8y)\hat{\mathbf{i}} + (-8x - 8 + 6z)\hat{\mathbf{j}} + 6y\hat{\mathbf{k}}]$

The value of $\mathbf{E}$ at coordinate (1, 1, 1)

$\mathbf{E} = -[-2\hat{\mathbf{i}} - 10\hat{\mathbf{j}} + 6\hat{\mathbf{k}}]$

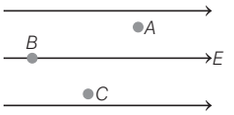
So, $\mathbf{E}_{net} = \sqrt{(-2)^2 + (-10)^2 + 6^2}$

$= 2\sqrt{35}$ N/C

and force on charge q due to $\mathbf{E}_{net}$ is given by

$F = q\,\mathbf{E}_{net} = 2\times 2\sqrt{35} = 4\sqrt{35}$ N

11 A, B and C are three points in a uniform electric field. The electric potential is **[NEET 2013]**



(a) maximum at A

(b) maximum at B

(c) maximum at C

(d) same at all the three points A, B and C

Ans. *(b)*

The electric field is maximum at B, because electric field is directed along decreasing potential $V_B > V_C > V_A$.

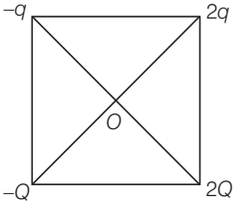
12 Four point charges $-Q, -q, 2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero, is **[CBSE AIPMT 2012]**

(a) $Q = -q$ (b) $Q = -\frac{1}{q}$

(c) $Q = q$ (d) $Q = \frac{1}{q}$

Ans. *(a)*

As, shown in figure



If potential at centre is zero, then

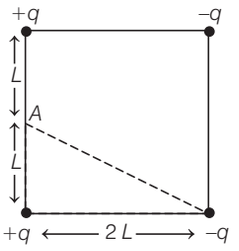
$V_1 + V_2 + V_3 + V_4 = 0$

$\Rightarrow -\frac{kQ}{r} - \frac{kq}{r} + \frac{k2Q}{r} + \frac{k2q}{r} = 0$

$\Rightarrow \quad -Q - q + 2q + 2Q = 0$

$\therefore \quad Q = -q$

13 Four electric charges $+q, +q, -q$ and $-q$ are placed at the corners of a square of side $2L$ (see figure). The electric potential at point A, mid-way between the two charges $+q$ and $+q$ is **[CBSE AIPMT 2011]**



(a) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1 + \frac{1}{\sqrt{5}}\right)$

(b) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1 - \frac{1}{\sqrt{5}}\right)$

(c) zero

(d) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}(1 + \sqrt{5})$

Ans. *(b)*

Potential at any distance r due to a point charge is given by,

$V = \frac{kq}{r}$ $\left[k = \frac{1}{4\pi\varepsilon_0}\right]$

Given, $V = 2V_{positive} + 2V_{negative}$

$= \frac{1}{4\pi\varepsilon_0}\left[\frac{2q}{L} - \frac{2q}{L\sqrt{5}}\right]$

$V = \frac{2q}{4\pi\varepsilon_0 L}\left(1 - \frac{1}{\sqrt{5}}\right)$

14 The electric potential at a point (x, y, z) is given by $V = -x^2 y - xz^3 + 4$ The electric field $\mathbf{E}$ at that point is **[CBSE AIPMT 2009]**

(a) $\mathbf{E} = (2xy + z^3)\hat{\mathbf{i}} + x^2\hat{\mathbf{j}} + 3xz^2\hat{\mathbf{k}}$

(b) $\mathrm{E} = 2xy\hat{\mathbf{i}} + (x^2 + y^2)\hat{\mathbf{j}} + (3xz - y^2)\hat{\mathbf{k}}$

(c) $\mathbf{E} = z^3\hat{\mathbf{i}} + xyz\hat{\mathbf{j}} + z^2\hat{\mathbf{k}}$

(d) $\mathbf{E} = (2xy - z^3)\hat{\mathbf{i}} + xy^2\hat{\mathbf{j}} + 3z^2x\hat{\mathbf{k}}$

Ans. *(a)*

Potential gradient relates with electric field according to the following relation,

$E = \frac{-dV}{dr}$

$\mathrm{E} = -\frac{dV}{dr}$

As $V = -x^2 y - xz^3 + 4$

So, $\mathbf{E} = -\frac{dV}{dx}\hat{\mathbf{i}} - \frac{dV}{dy}\hat{\mathbf{j}} - \frac{dV}{dz}\hat{\mathbf{k}}$

$\mathbf{E} = (2xy + z^3)\hat{\mathbf{i}} + x^2\hat{\mathbf{j}} + 3xz^2\hat{\mathbf{k}}$

15 Three concentric spherical shells have radii a, b and c $(a < b < c)$ and have surface charge densities $\sigma, -\sigma$ and σ respectively. If

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V_A, V_B and V_C denote the potentials of the three shells, then for $c = a + b$, we have

[CBSE AIPMT 2009]

(a) $V_C = V_A \neq V_B$ (b) $V_C = V_B \neq V_A$
(c) $V_C \neq V_B \neq V_A$ (d) $V_C = V_B = V_A$

Ans. *(d)*

$$V_A = \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi a^2}{a} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{b} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{\sigma 4\pi c^2}{c}$$

$$= \frac{\sigma}{\varepsilon_0}(a - b + c) = \frac{\sigma}{\varepsilon_0}(2a) \quad (\because c = a + b)$$

$$V_B = \frac{1}{4\pi\varepsilon_0}\cdot\frac{\sigma 4\pi a^2}{c} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{b} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{\sigma 4\pi c^2}{c}$$

$$= \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - b + c\right) = \frac{\sigma}{\varepsilon_0}(2a) \quad (\because c = a + b)$$

and $$V_C = \frac{1}{4\pi\varepsilon_0}\cdot\frac{\sigma 4\pi a^2}{c} - \frac{1}{4\pi\varepsilon_0}\frac{\sigma 4\pi b^2}{c} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{\sigma 4\pi c^2}{c}$$

$$= \frac{\sigma}{\varepsilon_0}\left(\frac{a^2}{c} - \frac{b^2}{c} + c\right) = \frac{\sigma}{\varepsilon_0}(2a) \quad (\because c = a + b)$$

Hence, $V_A = V_C = V_B$

16 The electric potential at a point in free space due to a charge Q coulomb is $Q \times 10^{11}$ V. The electric field at that point is

[CBSE AIPMT 2008]

(a) $4\pi\varepsilon_0 Q \times 10^{22}$ V/m
(b) $12\pi\varepsilon_0 Q \times 10^{20}$ V/m
(c) $4\pi\varepsilon_0 Q \times 10^{20}$ V/m
(d) $12\pi\varepsilon_0 Q \times 10^{22}$ V/m

Ans. *(a)*

As potential at any point due to a point charge is given by,

$$V = \frac{kQ}{r} \qquad \left[k = \frac{1}{4\pi\varepsilon_0}\right]$$

$$V = \frac{1}{4\pi\varepsilon_0} \times \frac{Q}{r}$$

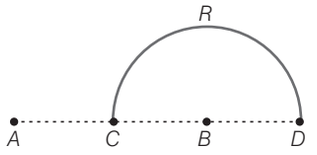
$$E = \frac{1}{4\pi\varepsilon_0} \times \frac{Q}{r^2}$$

$$E = \frac{4\pi\varepsilon_0 V^2}{Q} = 4\pi\varepsilon_0 \times \frac{Q^2 \times 10^{22}}{Q}$$

$$E = 4\pi\varepsilon_0 Q \times 10^{22} \text{ V/m}$$

17 Charges $+q$ and $-q$ are placed at points A and B respectively which are a distance $2L$ apart, C is the midpoint between A and B. The work done in moving a charge $+Q$ along the semicircle CRD is

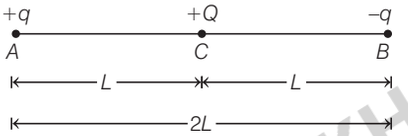
[CBSE AIPMT 2007]



(a) $\frac{qQ}{4\pi\varepsilon_0 L}$ (b) $\frac{qQ}{2\pi\varepsilon_0 L}$
(c) $\frac{qQ}{6\pi\varepsilon_0 L}$ (d) $-\frac{qQ}{6\pi\varepsilon_0 L}$

Ans. *(d)*

In case I, when charge $+Q$ is situated at C.



Electric potential energy of system,

$$U_1 = \frac{1}{4\pi\varepsilon_0}\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)Q}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}$$

In case II, when charge $+Q$ is moved from C to D.

Electric potential energy of system in that case,

$$U_2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(q)(-q)}{2L} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{qQ}{3L} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)(Q)}{L}$$

As we know that work done in moving a charge is equal to change in potential energy between the points it has been moved.

Work done, $\Delta U = U_2 - U_1$

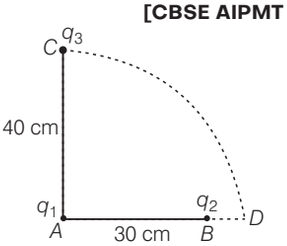
$$= \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{qQ}{3L} - \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right) - \left(-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2L} - \frac{1}{4\pi\varepsilon_0}\cdot\frac{qQ}{L} + \frac{1}{4\pi\varepsilon_0}\frac{qQ}{L}\right)$$

$$= \frac{qQ}{4\pi\varepsilon_0}\cdot\left(\frac{1}{3L} - \frac{1}{L}\right) = \frac{qQ}{4\pi\varepsilon_0}\frac{(1-3)}{3L}$$

$$= \frac{-2qQ}{12\pi\varepsilon_0 L} = -\frac{qQ}{6\pi\varepsilon_0 L}$$

18 Two charges q_1 and q_2 are placed 30 cm apart, as shown in the figure. A third charge q_3 is moved along the arc of a circle of radius 40 cm from C to D. The change in the potential energy of the system is $\frac{q_3}{4\pi\varepsilon_0}k$, where k is

[CBSE AIPMT 2005]



(a) $8q_2$ (b) $8q_1$
(c) $6q_2$ (d) $6q_1$

Ans. *(a)*

When charge q_3 is at C, then its potential energy is

$$U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.5}\right)$$

When charge q_3 is at D, then potential energy is

$$U_D = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1}\right)$$

Hence, change in potential energy

$$\Delta U = U_D - U_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} - \frac{q_2 q_3}{0.5}\right)$$

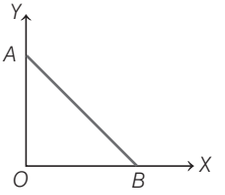
but $$\Delta U = \frac{q_3}{4\pi\varepsilon_0}k$$

$$\frac{q_3}{4\pi\varepsilon_0}k = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} - \frac{q_2 q_3}{0.5}\right)$$

$$k = q_2(10 - 2) = 8q_2$$

19 As per this diagram a point charge $+q$ is placed at the origin O. Work done in taking another point charge $-Q$ from the point A [coordinates $(0, a)$] to another point B [coordinates $(a, 0)$] along the straight path AB is

[CBSE AIPMT 2005]



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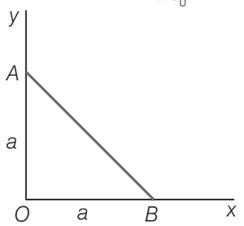
(a) zero
(b) $\left(\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$
(c) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right).\frac{a}{\sqrt{2}}$
(d) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$

Ans. *(a)*

Potential at A, $V_A = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$



Potential at B,

$$V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$$

Thus, work done in carrying a test charge $-Q$ from A to B

$$W = (V_A - V_B)(-Q) = 0$$

20 A bullet of mass 2 g is having a charge of 2 μC. Through what potential difference must it be accelerated, starting from rest, to acquire a speed of 10 m/s?

[CBSE AIPMT 2004]

(a) 5 kV (b) 50 kV (c) 5 V (d) 50 V

Ans. *(b)*

Kinetic energy of bullet $= qV$

$$\begin{bmatrix} q = \text{charge on bullet} \\ V = \text{potential difference} \end{bmatrix}$$

From energy conservation,

$$\frac{1}{2}mv^2 = qV \Rightarrow V = \frac{mv^2}{2q}$$

Given, $m = 2\text{ g} = 2\times10^{-3}\text{ kg}, v = 10\text{ m/s}$,

$q = 2\mu\text{C} = 2\times10^{-6}\text{ C}$

Substituting the values in relation for V, we obtain

$$V = \frac{2\times10^{-3}\times(10)^2}{2\times2\times10^{-6}}$$

$$= 50\times10^3\text{ V} = 50\text{ kV}$$

21 Some charge is being given to a conductor, then its potential is

[CBSE AIPMT 2002]

(a) maximum at surface
(b) maximum at centre
(c) same throughout the conductor
(d) maximum somewhere between surface and centre

Ans. *(c)*

Concept An equipotential surface has a constant value of potential at all points on its surface. The surface and interior of a charged conductor is equipotential. Therefore, the potential is same throughout the charged conductor.

22 Identical charges $(-q)$ are placed at each corners of a cube of side b, then the electrostatic potential energy of charge $(+q)$ placed at the centre of the cube will be

[CBSE AIPMT 2002]

(a) $-\frac{4\sqrt{2}q^2}{\pi\varepsilon_0}$ (b) $\frac{8\sqrt{2}q^2}{\pi\varepsilon_0 b}$
(c) $-\frac{4q^2}{\sqrt{3}\pi\varepsilon_0 b}$ (d) $\frac{8\sqrt{2}q^2}{4\pi\varepsilon_0 b}$

Ans. *(c)*

Electrostatic potential energy of charge $+q$ placed at the centre of cube is

$$U = 8\times\frac{1}{4\pi\varepsilon_0}\times\frac{q(-q)}{\text{half - diagonal distance}}$$

$$= 8\times\frac{1}{4\pi\varepsilon_0}\frac{-q^2}{b\frac{\sqrt{3}}{2}}$$

$$\begin{bmatrix} \text{diagonal of cube} = \sqrt{3}b \\ \text{where, } b = \text{side of cube} \end{bmatrix}$$

$$= \frac{-4q^2}{\sqrt{3}\pi\varepsilon_0 b}$$

23 In bringing an electron towards another electron, the electrostatic potential energy of the system

[CBSE AIPMT 1999]

(a) decreases (b) increases
(c) remains same (d) becomes zero

Ans. *(b)*

The electron has negative charge. When an electron is brought towards another electron, then due to same negative charges repulsive force is produced between them. So, to bring them closer a work is done against this repulsive force. This work is stored in the form of electrostatic potential energy. Thus, electrostatic potential energy of system increases.

Alternative

Electrostatic potential energy of system of two electrons

$$U = \frac{1}{4\pi\varepsilon_0}\frac{(-e)(-e)}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

Thus, as r decreases, potential energy U increases.

24 An electron of mass m and charge e is accelerated from rest through a potential difference of V volt in vacuum. Its final speed will be

[CBSE AIPMT 1996]

(a) $\frac{eV}{2m}$ (b) $\frac{eV}{m}$
(c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{eV}{2m}}$

Ans. *(c)*

In J J Thomson's method, as the electron beam is accelerated from cathode to anode, its potential energy at the cathode appears as gain in kinetic energy at the anode. If V is the potential difference between cathode and anode, then potential energy of electron at cathode

$= \text{charge}\times\text{potential difference} = eV$

Gain in kinetic energy of electron at anode

$$= \frac{1}{2}mv^2$$

According to conservation of energy, we have

$$eV = \frac{1}{2}mv^2$$

$$\therefore \quad v = \sqrt{\left(\frac{2eV}{m}\right)}$$

25 There is an electric field E in x-direction. If the work done on moving a charge of 0.2 C through a distance of 2 m along a line making an angle 60° with x-axis is 4 J, then what is the value of E ?

[CBSE AIPMT 1995]

(a) 3 N/C (b) 4 N/C
(c) 5 N/C (d) 20 N/C

Ans. *(d)*

Work done in moving the charge,

$$W = Fd\cos\theta$$

As $F = qE$

$$\therefore \quad W = qEd\cos\theta$$

or $$E = \frac{W}{qd\cos\theta}$$

Here, $q = 0.2\text{ C}, d = 2\text{ m}$

$\theta = 60°, W = 4\text{ J}$

$$\therefore \quad E = \frac{4}{0.2\times2\times\cos60°}$$

$$= 20\text{ N/C}$$

Alternative

As we know that potential at any point in the direction of θ and electric field $\mathbf{E}$ is given by $dV = -\mathbf{E}\cdot d\mathbf{r}$

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$\left(\begin{matrix}\text{negative sign indicates decreasing}\\ \text{potential in direction of electric field}\end{matrix}\right)$

So, for the given situation

$dr = d\cos\theta$

So, $dV = Ed\cos\theta$

Now, work done for a charge moving in potential difference dV is given by

$W = q\,dV$

$\Rightarrow \quad W = qEd\cos\theta$

Given, $q = 0.2\text{ C}, d = 2\text{ m}, \theta = 60°, W = 4\text{ J}$

So, $4\text{ J} = 0.2 \times E \times 2 \times \cos 60°$

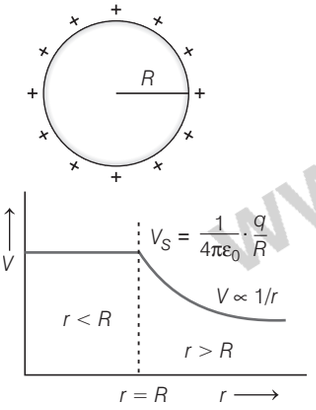
$\Rightarrow \quad E = \dfrac{4}{0.2\times 2} \times 2 = 20\text{ J}$

26 A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 80 V. The potential at the centre of the sphere is **[CBSE AIPMT 1994]**

(a) zero (b) 80 V
(c) 800 V (d) 8 V

Ans. *(b)*

In case of spherical metal conductor hollow or solid for an internal point (i.e. $r < R$) potential everywhere inside is same. It is maximum at the surface of sphere and further going out of sphere its value decreases.



So, according to above graph

$V_{in} = V_{centre} = V_{surface}$

$= \dfrac{1}{4\pi\varepsilon_0} \times \dfrac{q}{R} = 80\text{ V}$

$[\because V_{surface} = 80\text{ V}]$

27 Two concentric spheres of radii R and r have similar charges with equal surface charge densities (σ). What is the electric potential at their common centre ? **[CBSE AIPMT 1991]**

(a) $\dfrac{\sigma}{\varepsilon_0}$ (b) $\dfrac{\sigma}{\varepsilon_0}(R - r)$

(c) $\dfrac{\sigma}{\varepsilon_0}(R + r)$ (d) None of these

Ans. *(c)*

Let Q and q be the charges on the spheres. The potential at the common centre will be

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{R}\right) + \frac{4}{4\pi\varepsilon_0}\left(\frac{q}{r}\right)$$

$$= \frac{1}{\varepsilon_0}\left[\frac{Q}{4\pi R^2} \times R + \frac{q}{4\pi r^2} \times r\right]$$

But, $\dfrac{Q}{4\pi R^2} = \dfrac{q}{4\pi r^2} = \sigma$

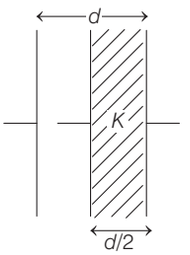
$\therefore \quad V = \dfrac{1}{\varepsilon_0}[\sigma R + \sigma r]$

$= \dfrac{\sigma}{\varepsilon_0}(R + r)$

TOPIC 2

Capacitors and Capacitance

28 A parallel plate capacitor having cross-sectional area A and separation d has air in between the plates. Now, an insulating slab of same area but thickness $d/2$ is inserted between the plates as shown in figure having dielectric constant $K(=4)$. The ratio of new capacitance to its original capacitance will be **[NEET (Oct.) 2020]**



(a) 2 : 1 (b) 8 : 5
(c) 6 : 5 (d) 4 : 1

Ans. *(b)*

Capacitance of parallel plate capacitor when medium is air

$$C_0 = \frac{\varepsilon_0 A}{d} \qquad \ldots(i)$$

According to second condition,

$A' = A, t = d/2, k = 4$

$\therefore$ Capacitance, $C = \dfrac{\varepsilon_0 A}{(d - t) + \dfrac{t}{k}}$

$$= \frac{\varepsilon_0 A}{\left(d - \frac{d}{2}\right) + \frac{d/2}{4}}$$

$$= \frac{\varepsilon_0 A}{\frac{d}{2} + \frac{d}{8}} = \frac{8}{5} \cdot \frac{\varepsilon_0 A}{d}$$

$\therefore \quad \dfrac{C}{C_0} = \dfrac{\frac{8}{5}\cdot\frac{\varepsilon_0 A}{d}}{\frac{\varepsilon_0 A}{d}} \Rightarrow \dfrac{C}{C_0} = \dfrac{8}{5}$

$\Rightarrow \quad C : C_0 = 8 : 5$

29 The capacitance of a parallel plate capacitor with air as medium is 6 μF. With the introduction of a dielectric medium, the capacitance becomes 30 μF. The permittivity of the medium is ($\varepsilon_0 = 8.85 \times 10^{-12}\text{ C}^2\text{N}^{-1}\text{m}^{-2}$) **[NEET (Sep.) 2020]**

(a) $1.77 \times 10^{-12}\text{ C}^2\text{N}^{-1}\text{m}^{-2}$
(b) $0.44 \times 10^{-10}\text{ C}^2\text{N}^{-1}\text{m}^{-2}$
(c) $5.00\text{ C}^2\text{N}^{-1}\text{m}^{-2}$
(d) $0.44 \times 10^{-13}\text{ C}^2\text{N}^{-1}\text{m}^{-2}$

Ans. *(b)*

Given, $C_0 = 6\mu\text{F}$

$C_m = 30\mu\text{F}$

$\therefore$ As, dielectric constant

$$K = \varepsilon_r = \frac{C_m}{C_0} = \frac{30}{6} = 5$$

Permittivity of the medium,

$\varepsilon_m = K \times \varepsilon_0 = 5 \times \varepsilon_0$

$= 5 \times 8.85 \times 10^{-12}$

$= 0.44 \times 10^{-10}\text{ C}^2\text{N}^{-1}\text{m}^{-2}$

Hence, correct option is (b).

30 The electrostatic force between the metal plates of an isolated parallel plate capacitor C having a charge Q and area A, is **[NEET 2018]**

(a) proportional to the square root of the distance between the plates
(b) linearly proportional to the distance between the plates
(c) independent of the distance between the plates
(d) inversely proportional to the distance between the plates

Ans. *(c)*

As we know that, the total work done in transferring a charge to a parallel plate capacitor is given as

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$$W = \frac{Q^2}{2C} \quad ...(i)$$

where, C is the capacitance of the capacitor.

We can also wirte a relation for work done as,

$$W = F \cdot d \quad ...(ii)$$

where, F is the electrostatic force between the plates of capacitor and d is the distance between the plates.

From Eqs. (i) and (ii), we get

$$W = \frac{Q^2}{2C} = Fd$$

$$\Rightarrow \quad F = \frac{Q^2}{2Cd} \quad ...(iii)$$

As, the capacitance of a parallel plate is given as

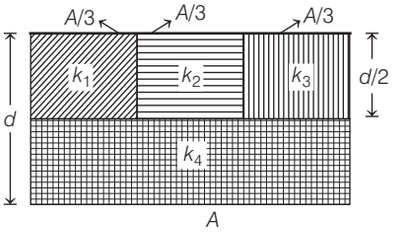
$$C = \frac{\varepsilon_0 A}{d}$$

Substituting the value of C in Eq. (iii), we get

$$F = \frac{Q^2 d}{2\varepsilon_0 Ad} = \frac{Q^2}{2\varepsilon_0 A}$$

This means, electrostatic force is independent of the distance between the plates.

31 A parallel-plate capacitor of area A, plate separation d and capacitance C is filled with four dielectric materials having dielectric constants k_1, k_2, k_3 and k_4 as shown in the figure below. If a single dielectric material is to be used to have the same capacitance C in this capacitor, then its dielectric constant k is given by **[NEET 2016]**



(a) $k = k_1 + k_2 + k_3 + 3k_4$

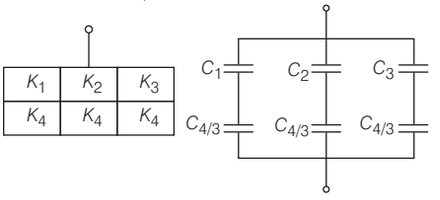
(b) $k = \frac{2}{3}(k_1 + k_2 + k_3) + 2k_4$

(c) $\frac{2}{k} = \frac{3}{k_1 + k_2 + k_3} + \frac{1}{k_4}$

(d) $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \frac{3}{2k_4}$

Ans. *(*)*

Given capacitor is equivalent to capacitors K_1, K_2 and K_3 in parallel and part of K_4 in series with them



$$\frac{1}{C_1} + \frac{3}{C_4} = \frac{3d}{2K_1\varepsilon_0 A} + \frac{3d}{2K_4\varepsilon_0 A}$$

$$= \frac{3d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_4}\right]$$

$$\Rightarrow \quad C_{eq} = \frac{K\varepsilon_0 A}{d}$$

$$= \frac{2\varepsilon_0 A}{3d}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

$$K = \frac{2}{3}\left[\frac{K_1K_4}{K_1 + K_4} + \frac{K_2K_4}{K_2 + K_4} + \frac{K_3K_4}{K_3 + K_4}\right]$$

No option is matching.

32 A parallel plate air capacitor has capacity C, distance of separation between plates is d and potential difference V is applied between the plates. Force of attraction between the plates of the parallel plate air capacitor is **[CBSE AIPMT 2015]**

(a) $\frac{C^2V^2}{2d}$ (b) $\frac{CV^2}{2d}$ (c) $\frac{CV^2}{d}$ (d) $\frac{C^2V^2}{2d^2}$

Ans. *(b)*

Force between plates of parallel capacitor,

$$F = q\,E = q\left[\frac{\sigma}{2\varepsilon_0}\right]$$

$\because$ Surface charge density $\sigma = \frac{q}{A}$

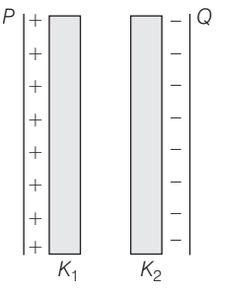
$$\therefore \quad F = q\left[\frac{q}{2A\varepsilon_0}\right] \Rightarrow F = \frac{q^2}{2A\varepsilon_0}$$

So, net charge across a capacitor, $q = CV$

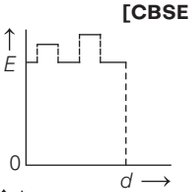
$$F = \frac{C^2V^2}{2A\varepsilon_0} \qquad \left[C = \frac{A\varepsilon_0}{d}\right]$$

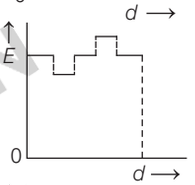
$$\Rightarrow \quad F = \frac{\left(\frac{A\varepsilon_0}{d}\right) \times CV^2}{2\,A\,\varepsilon_0} = \frac{CV^2}{2d}$$

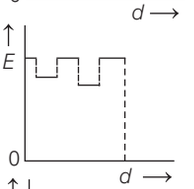
33 Two thin dielectric slabs of dielectric constants K_1 and K_2 $(K_1 < K_2)$ are inserted between plates of a parallel plate capacitor, as shown in the figure.

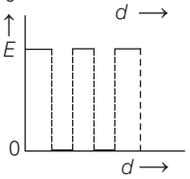


The variation of electric field E between the plates with distance d as measured from plate P is correctly shown by **[CBSE AIPMT 2014]**

(a)


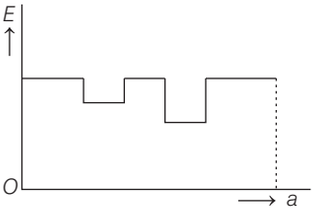
(b)


(c)


(d)


Ans. *(c)*

Graph (c) will be the right graph, the electric field inside the dielectrics will be less than the electric field outside the dielectrics. The electric field inside the dielectrics could not be zero.



As $K_2 > K_1$, the drop in electric field for K_2 dielectric must be more than K_1.

34 A parallel plate air capacitor is charged to a potential difference of V volts. After disconnecting the charging battery the distance

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between the plates of the capacitor is increased using an insulating handle. As a result the potential difference between the plates **[CBSE AIPMT 2006]**

(a) decreases (b) does not change
(c) becomes zero (d) increases

Ans. *(d)*

If the battery is removed after charging, then the charge stored in the capacitor remains constant.

$$q = \text{constant}$$

Change in capacitance,

$$C' = \frac{\varepsilon_0 A}{d'}$$

As $d' > d$

Hence, $C' < C$

As, potential difference between the plates of capacitor is given by

$$V = \frac{q}{C}$$

So, for the new capacitor formed

$$V' \propto \frac{1}{C'} \quad [q = \text{constant}]$$

As capacitance decreases, so potential difference increases.

NOTE

If the battery remains connected, the charge stored increases. Also, the potential difference V becomes constant.

35 A parallel plate condenser with oil (dielectric constant 2) between the plates has capacitance C. If oil is removed, the capacitance of capacitor becomes **[CBSE AIPMT 1999]**

(a) $\sqrt{2}C$ (b) $2C$
(c) $\frac{C}{\sqrt{2}}$ (d) $\frac{C}{2}$

Ans. *(d)*

The capacitance of a parallel plate capacitor with dielectric (oil) between its plates is

$$C = \frac{K\varepsilon_0 A}{d} \quad ...(i)$$

where, ε_0 = electric permittivity of free space

K = dielectric constant of oil

A = area of each plate of capacitor

d = distance between two plates

When dielectric (oil) is removed, so capacitance of capacitor becomes,

$$C_0 = \frac{\varepsilon_0 A}{d} \quad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

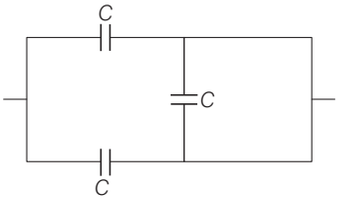
$$C = KC_0$$

$$\Rightarrow \quad C_0 = \frac{C}{K} = \frac{C}{2} \quad (K = 2)$$

TOPIC 3

Combination of Capacitors and Energy Stored in a Capacitor

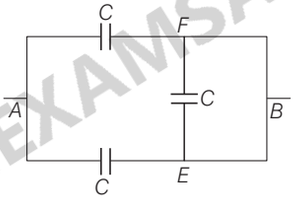
36 The equivalent capacitance of the combination shown in the figure is **[NEET 2021]**



(a) $3C$ (b) $2C$
(c) $\frac{C}{2}$ (d) $\frac{3C}{2}$

Ans. *(b)*

Consider the nodes be A, B, E and F as shown in the figure

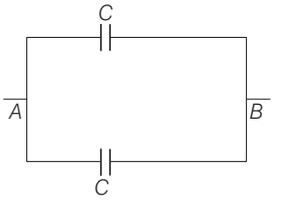


The potential at node A is equal to the potential at node B.

Similarly, the potential at F is equal to the potential at node E.

So, there is no potential difference between the EF arms, thus, no current (hence, charge) will flow in the circuit.

So, EF behave as open circuit.



Now, the two capacitors are arranged in parallel.

The net equivalent capacitors,

$$C_{eq} = C_1 + C_2$$

$$\Rightarrow \quad C_{eq} = C + C$$

$$\Rightarrow \quad C_{eq} = 2C$$

37 A parallel plate capacitor has a uniform electric field $\mathbf{E}$ in the space between the plates. If the distance between the plates is d and the area of each plate is A, the energy stored in the capacitor is (ε_0 = permittivity of free space). **[NEET 2021]**

(a) $\frac{1}{2}\varepsilon_0 E^2$ (b) $\varepsilon_0 EAd$
(c) $\frac{1}{2}\varepsilon_0 E^2 Ad$ (d) $\frac{E^2 Ad}{\varepsilon_0}$

Ans. *(c)*

We know that, capacitance of a parallel plate capacitor,

$$C = \frac{A\varepsilon_0}{d} \quad ...(i)$$

The relation between the potential difference (V) and electric field (E),

$$V = Ed \quad ...(ii)$$

The energy stored in the capacitor,

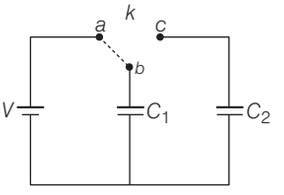
$$U = \frac{1}{2}CV^2$$

$$U = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2$$

[$\because$ from Eqs. (i) and (ii)]

$$U = \frac{1}{2}(\varepsilon_0 A)(E)^2 d = \frac{1}{2}\varepsilon_0 E^2 Ad$$

38 Two identical capacitors C_1 and C_2 of equal capacitance are connected as shown in the circuit. Terminals a and b of the key k are connected to charge capacitor C_1 using battery of emf V volt. Now, disconnecting a and b the terminals b and c are connected. Due to this, what will be the percentage loss of energy? **[NEET (Odisha) 2019]**



(a) 75% (b) 0% (c) 50% (d) 25%

Ans. *(c)*

When C_1 is connected to voltage source, it is charged to a potential V and this will be stored as a potential energy in the capacitor given by

$$U = \frac{1}{2}CV^2$$

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When key is disconnected from battery and b and c are connected, the charge will be transformed from the capacitor C_1 to capacitor C_2, then

The loss of energy due to redistribution of charge is given by

$$\Delta U = \frac{C_1C_2}{2(C_1+C_2)}(V_1-V_2)^2$$

$$= \frac{C\times C}{2(C+C)}(V-0)^2 = \frac{1}{4}CV^2 \quad [\because C_1 = C_2]$$

$$\therefore \text{Percentage loss} = \frac{\Delta U}{U}\times 100$$

$$= \frac{\frac{1}{4}CV^2}{\frac{1}{2}CV^2}\times 100 = 50\%$$

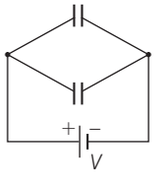
39 A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system **[NEET 2017]**

(a) increases by a factor of 4
(b) decreases by a factor of 2
(c) remains the same
(d) increases by a factor of 2

Ans. *(d)*

Thinking Process Energy stored in a system of capacitors

$$= \Sigma \frac{1}{2}CV^2$$



Also, potential drop remains same in parallel across both capacitors.
Initially stored energy

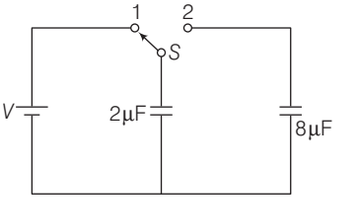
$$U_1 = \frac{1}{2}CV^2$$

Finally, potential drop across each capacitor will be still V.
So, finally stored energy

$$U_2 = \frac{1}{2}CV^2 + \frac{1}{2}CV^2 = \frac{1}{2}(2C)V^2$$

$$= 2\left(\frac{1}{2}CV^2\right) = 2U_1$$

40 A capacitor of 2μF is charged as shown in the figure. When the switch S is turned to position 2, the percentage of its stored energy dissipated is **[NEET 2016]**



(a) 20% (b) 75%
(c) 80% (d) 0%

Ans. *(c)*

Consider the given figure,
When the switch S is connected to point 1, then initial energy stored in the capacitor can be given as $= \frac{1}{2}(2\mu F)\times V^2$.

When the switch S is connected to point 2, energy dissipated on connection across 8 μF will be

$$= \frac{1}{2}\left(\frac{C_1C_2}{C_1+C_2}\right).V^2$$

$$= \frac{1}{2}\times\frac{2\mu F\times 8\mu F}{10\,\mu F}\times V^2$$

$$= \frac{1}{2}\times(1.6\,\mu F)\times V^2$$

Therefore, % loss of energy

$$= \frac{1.6}{2}\times 100 = 80\%.$$

41 A parallel plate air capacitor of capacitance C is connected to a cell of emf V and then disconnected from it. A dielectric slab of dielectric constant K, which can just fill the air gap of the capacitor, is now inserted in it. Which of the following is incorrect? **[CBSE AIPMT 2015]**

(a) The potential difference between the plates decreases K times
(b) The energy stored in the capacitor decreases K times
(c) The change in energy stored is $\frac{1}{2}CV^2\left(\frac{1}{K}-1\right)$
(d) The charge on the capacitor is not conserved

Ans. *(d)*

When a parallel plate air capacitor connected to a cell of emf V, then charge stored will be

$$q = CV \Rightarrow V = \frac{q}{C}$$

Also energy stored is $U = \frac{1}{2}CV^2 = \frac{q^2}{2C}$

As the battery is disconnected from the capacitor the charge will not be destroyed, i.e. $q' = q$ with the introduction of dielectric in the gap of capacitor the new capacitance will be

$$C' = CK \Rightarrow V' = \frac{q}{C'} = \frac{q}{CK}$$

The new energy stored will be

$$U' = \frac{q^2}{2CK} \Rightarrow \Delta U = U' - U$$

$$= \frac{q^2}{2C}\left(\frac{1}{K}-1\right) = \frac{1}{2}CV^2\left(\frac{1}{K}-1\right)$$

Hence, option (d) is incorrect

42 A parallel plate condenser has a uniform electric field E (V/m) in the space between the plates. If the distance between the plates is d(m) and area of each plate is $A(m^2)$, the energy (joule) stored in the condenser is **[CBSE AIPMT 2011]**

(a) $\frac{1}{2}\varepsilon_0 E^2$ (b) $\varepsilon_0 EAd$ (c) $\frac{1}{2}\varepsilon_0 E^2 Ad$ (d) E^2Ad/ε_0

Ans. *(c)*

As we know that the energy stored in the capacitor is given by,

$$U = \frac{1}{2}CV^2$$

$$\begin{bmatrix} C = \text{capacitance of capacitor} \\ V = \text{voltage across the plate} \end{bmatrix}$$

$$U = \frac{1}{2}\left(\frac{A\varepsilon_0}{d}\right)(Ed)^2$$

$$\left(\because C = \frac{\varepsilon_0 A}{d} \text{ and } V = Ed\right)$$

$$U = \frac{1}{2}\frac{\varepsilon_0 A}{d}(Ed)^2,\ U = \frac{1}{2}\varepsilon_0 E^2 Ad$$

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43 A series combination of n_1 capacitors, each of value C_1, is charged by a source of potential difference $4V$. When another parallel combination of n_2 capacitors, each of value C_2, is charged by a source of potential difference V, it has the same (total) energy stored in it, as the first combination has. The value of C_2, in terms of C_1, is then **[CBSE AIPMT 2010]**

(a) $\frac{2C_1}{n_1 n_2}$ (b) $16\frac{n_2}{n_1}C_1$

(c) $2\frac{n_2}{n_1}C_1$ (d) $\frac{16C_1}{n_1 n_2}$

Ans. *(d)*

Case I When the capacitors are joined in series,

$$U_{series} = \frac{1}{2}\frac{C_1}{n_1}(4V)^2$$

Case II When the capacitors are joined in parallel,

$$U_{parallel} = \frac{1}{2}(n_2\ C_2)V^2$$

Given, $U_{series} = U_{parallel}$

So, $\frac{1}{2}\frac{C_1}{n_1}(4V)^2 = \frac{1}{2}(n_2\ C_2)V^2$

$$\Rightarrow \quad C_2 = \frac{16C_1}{n_2\ n_1}$$

44 Three capacitors each of capacitance C and of breakdown voltage V are joined in series. The capacitance and breakdown voltage of the combination will be **[CBSE AIPMT 2009]**

(a) $\frac{C}{3}, \frac{V}{3}$ (b) $3C, \frac{V}{3}$

(c) $\frac{C}{3}, 3V$ (d) $3C, 3V$

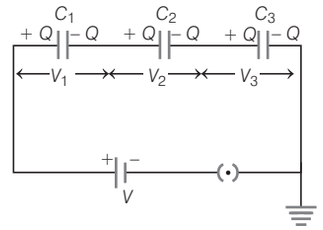
Ans. *(c)*

In series arrangement charge on each plate of all the capacitors have same magnitude. The potential difference is distributed inversely in the ratio of capacitors, i.e.

$$V = V_1 + V_2 + V_3 [\because V_1 = V_2 = V_3 = V]$$

Here, $V = 3V$

The equivalent capacitance C_s is given by



$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad [\because C_1 = C_2 = C_3 = C]$$

$$C_s = \frac{C}{3}$$

45 The energy required to charge a parallel plate condenser of plate separation d and plate area of cross-section A such that the uniform electric field between the plates E, is **[CBSE AIPMT 2008]**

(a) $\frac{1}{2}\frac{\varepsilon_0 E^2}{Ad}$ (b) $\frac{\varepsilon_0 E^2}{Ad}$

(c) $\varepsilon_0 E^2 Ad$ (d) $\frac{1}{2}\frac{\varepsilon_0 E^2}{Ad}$

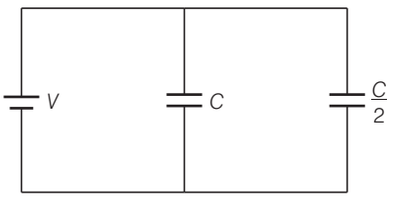
Ans. *(c)*

Energy of charged capacitor $= \frac{1}{2}CV^2$

Energy given by cell $= CV^2 = \frac{A\varepsilon_0}{d} \times (Ed)^2$

As, $V = Ed = A\varepsilon_0 E^2 d$

46 Two condensers, one of capacity C and the other of capacity $\frac{C}{2}$, are connected to a V volt battery, as shown.



The work done in charging fully both the condensers is **[CBSE AIPMT 2007]**

(a) $2CV^2$ (b) $\frac{1}{4}CV^2$

(c) $\frac{3}{4}CV^2$ (d) $\frac{1}{2}CV^2$

Ans. *(c)*

The two condensers in the circuit are in parallel order, hence

$$C' = C + \frac{C}{2} = \frac{3C}{2}$$

The work done in charging the equivalent capacitor is stored in the form of potential energy.

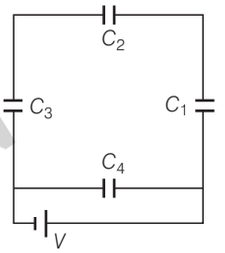
Hence, $W = U = \frac{1}{2}CV^2$

So, for the equivalent capacitor C'

$$= \frac{1}{2}\left(\frac{3C}{2}\right)V^2 \qquad \left(C' = \frac{3C}{2}\right)$$

$$= \frac{3}{4}CV^2$$

47 A network of four capacitors of capacity equal to $C_1 = C, C_2 = 2C$, $C_3 = 3C$ and $C_4 = 4C$ are connected to a battery as shown in the figure. The ratio of the charges on C_2 and C_4 is **[CBSE AIPMT 2005]**



(a) $\frac{22}{3}$ (b) $\frac{3}{22}$

(c) $\frac{7}{4}$ (d) $\frac{4}{7}$

Ans. *(a)*

The charge flowing through C_4 is

$$q_4 = C_4 \times V = 4CV$$

The series combination of C_1, C_2 and C_3 gives

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{2C} + \frac{1}{3C}$$

$$= \frac{6+3+2}{6C} = \frac{11}{6C} \Rightarrow C_{eq} = \frac{6C}{11}$$

Charge flowing through capacitors C_1, C_2 and C_3 will be same as they are in series.

So, q_1 flowing through C_1, C_2 and C_3 is given by

$$q_1 = C_{eq}V = \frac{6C}{11} \times V$$

Now, ratio of charge on C_4 and C_2 is given by,

$$\frac{q_4}{q_1} = \frac{4CV \times 11}{6CV} = \frac{22}{3}$$

48 Three capacitors each of capacity $4\mu F$ are to be connected in such a way that the effective capacitance is $6\mu F$. This can be done by **[CBSE AIPMT 2003]**

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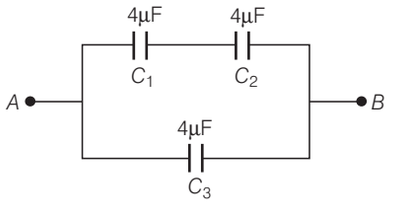
(a) connecting two in series and one in parallel
(b) connecting two in parallel and one in series
(c) connecting all of them in series
(d) connecting all of them in parallel

Ans. *(a)*

Given, $C_1 = C_2 = C_3 = 4\,\mu F$

(a) The network of three capacitors can be shown as

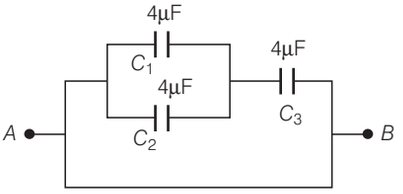


Here, C_1 and C_2 are in series and the combination of two is in parallel with C_3.

$$C_{net} = \frac{C_1 C_2}{C_1 + C_2} + C_3 = \left(\frac{4\times 4}{4+4}\right) + 4$$

$$= 2 + 4 = 6\mu F$$

(b) The corresponding network is shown in figure below



Here, C_1 and C_2 are in parallel and this combination is in series with C_3.

$$\text{So, } C_{net} = \frac{(C_1 + C_2)\times C_3}{(C_1 + C_2) + C_3} = \frac{(4+4)\times 4}{(4+4)+4}$$

$$= \frac{32}{12} = \frac{8}{3}\mu F$$

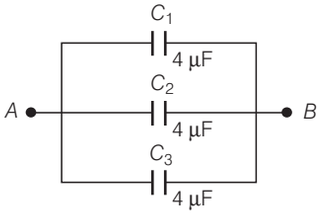
(c) The corresponding network is shown below.

All of three capacitors are in series.

$$\text{So, } \frac{1}{C_{net}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{3}{4}$$

$$\therefore \quad C = \frac{4}{3}\mu F$$

(d) The corresponding network is shown below.



All of them are in parallel.

So, $C_{net} = C_1 + C_2 + C_3$

$= 4 + 4 + 4 = 12\,\mu F$

Thus, options (a) is correct.

49 A capacitor of capacity C_1 is charged upto potential V volt and then connected in parallel to an uncharged capacitor of capacity C_2. The final potential difference across each capacitor will be **[CBSE AIPMT 2002]**

(a) $\frac{C_2 V}{C_1 + C_2}$ (b) $\frac{C_1 V}{C_1 + C_2}$

(c) $\left(1 + \frac{C_2}{C_1}\right)V$ (d) $\left(1 - \frac{C_2}{C_1}\right)V$

Ans. *(b)*

The common potential difference across two capacitors connected in parallel.

$$V_{eq} = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

Here, potential of charged capacitor $V_1 = V$,

potential of uncharged capacitor $V_2 = 0$

$$\therefore \quad V_{eq} = \frac{C_1 V}{C_1 + C_2}$$

50 In a parallel plate capacitor, the distance between the plates is d and potential difference across plates is V. Energy stored per unit volume between the plates of capacitor is **[CBSE AIPMT 2001]**

(a) $\frac{Q^2}{2V^2}$ (b) $\frac{1}{2}\frac{\varepsilon_0 V^2}{d^2}$

(c) $\frac{1}{2}\frac{V^2}{\varepsilon_0 d^2}$ (d) $\frac{1}{2}\varepsilon_0 \frac{V^2}{d}$

Ans. *(b)*

Energy stored, in parallel plate capacitor is given by

$$U = \frac{1}{2}\frac{q^2}{C}$$

but $\sigma = \frac{q}{A}$ and $C = \frac{\varepsilon_0 A}{d}$

$$\therefore \quad U = \frac{1}{2}\frac{(\sigma A)^2}{\left(\frac{\varepsilon_0 A}{d}\right)} = \frac{A\sigma^2 d}{2\varepsilon_0}$$

or $$= \frac{1}{2}\left(\frac{\sigma}{\varepsilon_0}\right)^2 \times \varepsilon_0 A d$$

or $$U = \frac{1}{2} E^2 \varepsilon_0 A d$$

Energy stored per unit volume i.e. energy density is thus given by

$$u = \frac{U}{V} = \frac{U}{Ad} = \frac{1}{2}\varepsilon_0 E^2$$

$$\Rightarrow \quad = \frac{1}{2}\varepsilon_0 \left(\frac{V}{d}\right)^2 = \frac{1}{2}\varepsilon_0 \frac{V^2}{d^2}$$

51 A capacitor is charged by connecting a battery across its plates. It stores energy U. Now the battery is disconnected and another identical capacitor is connected across it, then the energy stored by both capacitors of the system will be **[CBSE AIPMT 2000]**

(a) U (b) $\frac{U}{2}$ (c) $2U$ (d) $\frac{3}{2}U$

Ans. *(b)*

When a capacitor is charged by connecting a battery across its plates, the initial energy stored,

$$U = \frac{q^2}{2C}$$

When the battery is disconnected, then the charge remains constant i.e. q = constant. Now, another identical capacitor is connected across it i.e. the capacitors are connected in parallel, so the equivalent capacitance

$$C_{eq} = C_1 + C_2$$

$$= C + C = 2C$$

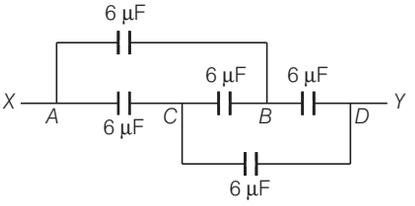
Thus, final energy stored by the system of capacitors,

$$U' = \frac{q^2}{2C_{eq}} \Rightarrow U' = \frac{q^2}{2(2C)}$$

$$U' = \frac{1}{2}U$$

$$\therefore \quad U' = \frac{U}{2}$$

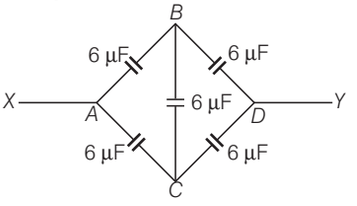
52 The effective capacitance between points X and Y of figure shown is **[CBSE AIPMT 1999]**



(a) 6 μF (b) 12 μF (c) 18 μF (d) 24 μF

Ans. *(a)*

The given circuit can be redrawn as,



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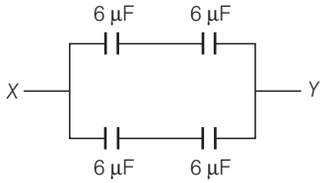
It is a balanced Wheatstone's bridge $\left(\text{as } \frac{C_{AB}}{C_{BD}} = \frac{C_{AC}}{C_{CD}} = \frac{6}{6}\right)$.

So, potential of B and C are equal and a 6 μF capacitor between B and C is ineffective. The simplified circuit is shown as below.



Capacitors of 6 μF and 6 μF in upper arms are in series order, so

$$C'_{eq_1} = \frac{6\times6}{6+6} = \frac{36}{12} = 3\,\mu F$$

Similarly, 6 μF and 6 μF in lower arms are in series order, so

$$C''_{eq_2} = \frac{6\times6}{6+6} = 3\,\mu F$$

Now, C'_{eq_1} and C''_{eq_2} are in parallel, hence

$$C_{net} = C'_{eq_1} + C''_{eq_2}$$
$$= 3 + 3 = 6\,\mu F$$

53 If the potential of a capacitor having capacity 6 μF is increased from 10 V to 20 V, then increase in its energy will be **[CBSE AIPMT 1995]**

(a) 4×10^{-4} J (b) 4×10^{-14} J
(c) 9×10^{-4} J (d) 12×10^{-6} J

Ans. ***(c)***

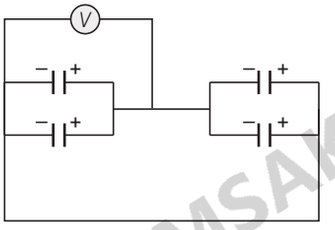
Energy stored in a charged capacitor is in the form of electric field energy and it resides in the dielectric medium between the plates. This energy stored in the capacitor is given by

$$U = \frac{1}{2}CV^2$$

If initial potential is V_1 and final potential is V_2, then increase in energy (ΔU)

$$\Delta U = \frac{1}{2}C(V_2^2 - V_1^2)$$
$$= \frac{1}{2}\times(6\times10^{-6})\times[(20)^2 - (10)^2]$$
$$= (3\times10^{-6})\times300 = 9\times10^{-4}\text{ J}$$

54 The four capacitors, each of 25 μF are connected as shown in figure. The DC voltmeter reads 200 V. The charge on each plate of capacitor is **[CBSE AIPMT 1994]**



(a) $\pm2\times10^{-3}$ C (b) $\pm5\times10^{-3}$ C
(c) $\pm2\times10^{-2}$ C (d) $\pm5\times10^{-2}$ C

Ans. ***(b)***

As from the given diagram, potential difference across each capacitor is 200 V.

So, charge on each plate of capacitor is given by

$$Q = \pm CV$$

[C = capacitance of capacitor; V = voltage or potential difference across the capactor]

$$= \pm25\times10^{-6}\times200 = \pm5\times10^{-3}\,C$$

55 A 4 μF capacitor is charged to 400 V and then its plates are joined through a resistance of 1 kΩ. The heat produced in the resistance is **[CBSE AIPMT 1989]**

(a) 0.16 J (b) 1.28 J
(c) 0.64 J (d) 0.32 J

Ans. ***(d)***

The energy stored in the capacitor $= \frac{1}{2}CV^2$.

This energy will be converted into heat in the resistor.

∴ Heat produced = energy stored

$$= \frac{1}{2}CV^2$$
$$= \frac{1}{2}\times4\times10^{-6}\times(400)^2$$
$$= 0.32\text{ J}$$

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17

Current Electricity

TOPIC 1
Ohm's Law and Resistance

01 **Column I** Gives certain physical terms associated with flow of current through a metallic conductor.
Column II Gives some mathematical relations involving electrical quantities. Match Column I and Column II with appropriate relations. **[NEET 2021]**

Column I		Column II	
A.	Drift velocity	1.	$\frac{m}{ne^2\rho}$
B.	Electrical resistivity	2.	nev_d
C.	Relaxation period	3.	$\frac{eE}{m}\tau$
D.	Current density	4.	$\frac{E}{J}$

Codes

	A	B	C	D
(a)	3	4	1	2
(b)	3	4	2	1
(c)	3	1	4	2
(d)	3	2	4	1

Ans. *(a)*

As we know that, the expression of the drift velocity,

$$v_d = \frac{eE}{m}\tau$$

Here, e is the electric charge,

E is the electric field,

m is the mass of an electron,

τ is the relaxation time.

Consider the conductor having length l, area of the cross-section A and the charge density n.

Electrical resistivity, $\rho = \frac{m}{ne^2\tau}$

Rearranging the above expression,

Relaxation period $\tau = \frac{m}{ne^2\rho}$

As we know that, the expression of current density,

$$J = \frac{I}{A} = \frac{neAv_d}{A} = nev_d$$

Again, $\frac{E}{J} = \frac{E}{\sigma E} = \frac{1}{\sigma} = \rho$

$\therefore$ Electrical resistivity, $\rho = \frac{E}{J}$

The correct match is A $\rightarrow$ 3, B $\rightarrow$ 4, C $\rightarrow$ 1, D $\rightarrow$ 2.

02 The effective resistance of a parallel connection that consists of four wires of equal length, equal area of cross-section and same material is 0.25 Ω. What will be the effective resistance if they are connected in series? **[NEET 2021]**

(a) 0.25 Ω (b) 0.5 Ω
(c) 1 Ω (d) 4 Ω

Ans. *(d)*

The four resistances have equal length, equal cross-sectional area and same material.

So, $R_1 = R_2 = R_3 = R_4 = R$ (say)

Given, the effective resistance,

$R_{eq} = 0.25\ \Omega$

For parallel arrangement,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$\Rightarrow \frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$

$$\Rightarrow \frac{1}{0.25\ \Omega} = \frac{4}{R}$$

$$\Rightarrow R = 1\ \Omega$$

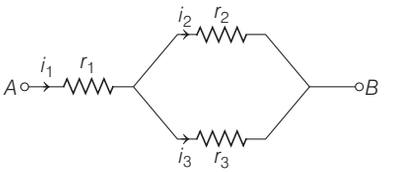
For series combination,

$$R_{eq} = R_1 + R_2 + R_3 + R_4$$

$$\Rightarrow R_{eq} = R + R + R + R$$

$$\Rightarrow R_{eq} = 4R \Rightarrow R_{eq} = 4(1) = 4\ \Omega$$

03 Three resistors having resistances r_1, r_2 and r_3 are connected as shown in the given circuit. The ratio $\frac{i_3}{i_1}$ of currents in terms of resistances used in the circuit is **[NEET 2021]**



(a) $\frac{r_1}{r_2 + r_3}$ (b) $\frac{r_2}{r_2 + r_3}$

(c) $\frac{r_1}{r_1 + r_2}$ (d) $\frac{r_2}{r_1 + r_3}$

Ans. *(b)*

According to the given circuit diagram in question,

$$i_1 = i_2 + i_3 \quad \text{...(i)}$$

In parallel arrangement of the electrical circuit,

the voltage remains same.

$\therefore$ $V = ir$ (using Ohm's law)

$$\Rightarrow i_2 r_2 = i_3 r_3$$

$$\Rightarrow i_2 = \frac{i_3 r_3}{r_2}$$

Substituting the values in the Eq. (i), we get

$$i_1 = \frac{i_3 r_3}{r_2} + i_3 \Rightarrow \frac{i_1}{i_3} = \frac{r_3}{r_2} + 1$$

$$\Rightarrow \frac{i_1}{i_3} = \frac{r_3 + r_2}{r_2} \Rightarrow \frac{i_3}{i_1} = \frac{r_2}{r_3 + r_2}$$

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04 Two solid conductors are made up of same material, have same length and same resistance. One of them has a circular cross-section of area A_1 and the other one has a square cross-section of area A_2. The ratio A_1/A_2 is

[NEET (Oct.) 2020]

(a) 1.5 (b) 1 (c) 0.8 (d) 2

Ans. *(b)*

Given, $R_1 = R_2, I_1 = I_2$

Since, resistance, $R = \rho \cdot \frac{l}{A}$

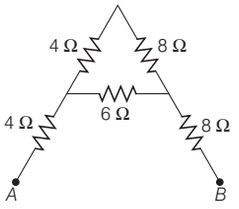
$$\Rightarrow \quad \frac{R_1}{R_2} = \frac{l_1}{l_2} \cdot \frac{A_2}{A_1} \Rightarrow \frac{R_1}{R_1} = \frac{l_1}{l_1} \cdot \frac{A_2}{A_1}$$

$$\Rightarrow \quad 1 = \frac{A_2}{A_1} \qquad [\because R_1 = R_2]$$

$$\Rightarrow \quad \frac{A_1}{A_2} = 1$$

05 The equivalent resistance between *A* and *B* for the mesh shown in the figure is

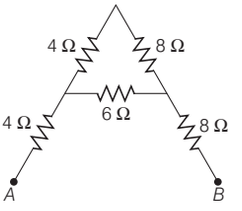
[NEET (Oct.) 2020]



(a) 7.2 Ω (b) 16 Ω (c) 30 Ω (d) 4.8 Ω

Ans. *(b)*

Equivalent resistance between points *A* and *B* is given as



$$R_{AB} = [(4+8)\,||\,6] + 4 + 8 = [12\,||\,6] + 12$$
$$= \left[\frac{12 \times 6}{12+6}\right] + 12 = [4] + 12 = 16\,\Omega$$

06 A charged particle having drift velocity of 7.5×10^{-4} ms^{-1} in an electric field of 3×10^{-10} Vm^{-1}, has a mobility (in $m^2V^{-1}s^{-1}$) of

[NEET (Sep.) 2020]

(a) 2.5×10^{6} (b) 2.5×10^{-6}
(c) 2.25×10^{-15} (d) 2.25×10^{15}

Ans. *(a)*

Given, drift velocity, $v_d = 7.5 \times 10^{-4}$ m/s

Electric field, $E = 3 \times 10^{-10}$ V-m

Mobility, $\mu = ?$

As, $$\mu = \frac{v_d}{E} = \frac{7.5 \times 10^{-4}}{3 \times 10^{-10}}$$

$$= 2.5 \times 10^{6}\,m^2V^{-1}s^{-1}$$

Hence, correct option is (a).

07 The color code of a resistance is given below **[NEET (Sep.) 2020]**

The values of resistance and tolerance respectively, are

(a) 47 kΩ, 10% (b) 4.7 kΩ, 5%
(c) 470 Ω, 5% (d) 470 kΩ, 5%

Ans. *(c)*

According to the carbon colour code for resistors,

Code of yellow = 4

Code of violet = 7

Code of brown, i.e. multiplier = 10^1

Code of gold, i.e. tolerance = ± 5%

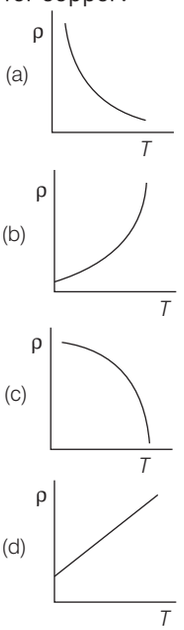
Hence, resistance of resistor

$= 47 \times 10^1\,\Omega$, 5%

$= 470\ \Omega$, 5%

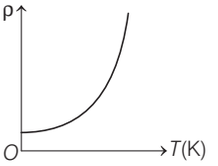
Hence, correct option is (c).

08 Which of the following graph represents the variation of resistivity (ρ) with temperature (*T*) for copper? **[NEET (Sep.) 2020]**



Ans. *(b)*

Resistivity of copper (a metal) as a function of temperature increases with the increase in temperature as shown below,



For copper at 0K, value of resistivity is 1.7×10^{-8} Ω-m.

Hence, correct option is (b).

09 Which of the following acts as a circuit protection device?

[NEET (National) 2019]

(a) Inductor (b) Switch
(c) Fuse (d) Conductor

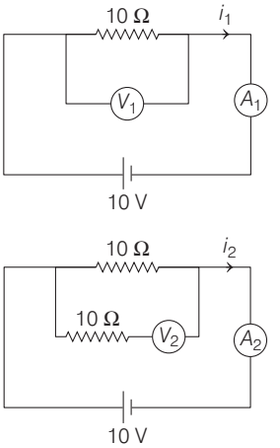
Ans. *(c)*

Among given devices fuse is used in electric circuit as a protective device.

It helps in preventing excessive amount of current to flow in the circuit or from short circuiting. It has low melting point and low resistivity, so when excess amount of current flow in the circuit, it melts and break the circuit.

10 In the circuits shown below, the readings of voltmeters and the ammeters will be

[NEET (National) 2019]



(a) $V_1 = V_2$ and $i_1 > i_2$ (b) $V_1 = V_2$ and $i_i = i_2$
(c) $V_2 > V_1$ and $i_1 > i_2$ (d) $V_2 > V_1$ and $i_1 = i_2$

Ans. *(b)*

For an ideal voltmeter, the resistance is infinite and for an ideal ammeter, the resistance is zero.

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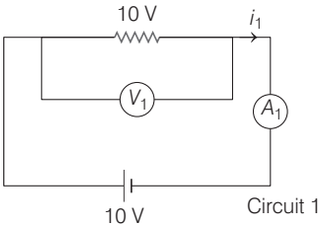


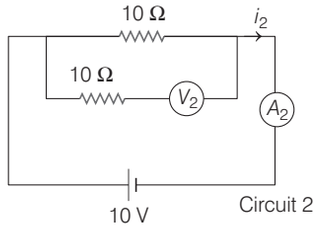
So, the current in circuit 1 is

$$R \times i = V \quad \text{or} \quad 10\, i_1 = 10$$

$$\Rightarrow \quad i_1 = \frac{10}{10} = 1\,\text{A}$$

$$\therefore \quad V_1 = i_1 \times R = 1 \times 10 = 10\,\text{V}$$

Similarly, for circuit 2, the addition of 10 Ω to voltmeter does not affect the current and hence



$$10\, i_2 = 10 \;\Rightarrow\; i_2 = \frac{10}{10} = 1\,\text{A}$$

$$V_2 = i_2 R = 1 \times 10 = 10\,\text{V}$$

$$\therefore \quad V_1 = V_2 \text{ and } i_1 = i_2$$

11 A carbon resistor of $(47 \pm 4.7)\ \text{k}\Omega$ is to be marked with rings of different colours for its identification. The colour code sequence will be **[NEET 2018]**

(a) Yellow - Green - Violet - Gold
(b) Yellow - Violet - Orange - Silver
(c) Violet - Yellow - Orange - Silver
(d) Green - Orange - Violet - Gold

Ans. *(b)*

Given, $R = (47 \pm 4.7)\,\text{k}\Omega$

$$= 47 \times 10^3 \pm 10\%\ \Omega$$

As per the colour code for carbon resistors, the colour assigned to numbers.

4 – Yellow
7 – Violet
3 – Orange

For ±10% accuracy, the colour is silver. Hence, the bands of colours on carbon resistor in sequence are yellow, violet, orange and silver.

Note To remember the colour code sequence for carbon resistor, the following sentence should be kept in memory. B B Roy of Great Britain has a Very Good Wife.

12 The resistance of a wire is R ohm. If it is melted and stretched to n times its original length, its new resistance will be **[NEET 2017]**

(a) nR (b) $\frac{R}{n}$ (c) $n^2 R$ (d) $\frac{R}{n^2}$

Ans. *(c)*

Thinking Process Volume of material remains same in stretching.

As volume remains same, $A_1 l_1 = A_2 l_2$

Now, given $l_2 = n l_1$

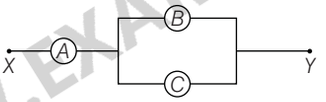
$\therefore$ New area $A_2 = \frac{A_1 l_1}{l_2} = \frac{A_1}{n}$

Resistance of wire after stretching

$$R_2 = \rho \frac{l_2}{A_2} = \rho \cdot \frac{n l_1}{A_1 / n}$$

$$= \left(\rho \frac{l_1}{A_1}\right) \cdot n^2 = n^2 \cdot R \left[\because R = \left(\rho \frac{l_1}{A_1}\right)\right]$$

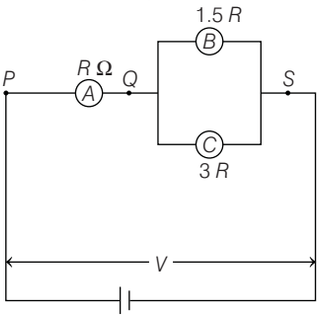
13 A, B and C are voltmeters of resistance R, $\mathbf{1.5}\,R$ and $3R$ respectively as shown in the figure. When some potential difference is applied between X and Y, the voltmeter readings are V_A, V_B and V_C respectively. Then, **[CBSE AIPMT 2015]**



(a) $V_A = V_B = V_C$ (b) $V_A \neq V_B = V_C$
(c) $V_A = V_B \neq V_C$ (d) $V_A \neq V_B \neq V_C$

Ans. *(a)*

The equivalent resistance between Q and S is given by



$$\frac{1}{R'} = \frac{1}{1.5R} + \frac{1}{3R} = \frac{2+1}{3R}$$

$$\Rightarrow \quad R' = R$$

Now, $V_{PQ} = V_A = IR$

Also $V_{QS} = V_B = V_C = IR$

Hence, $V_A = V_B = V_C$

14 Across a metallic conductor of non-uniform cross-section, a constant potential difference is applied. The quantity which remain constant along the conductor is **[CBSE AIPMT 2015]**

(a) current density (b) current
(c) drift velocity (d) electric field

Ans. *(b)*

As the cross-sectional area of the conductor is non-uniform so current density will be different.

As $I = JA$ ...(i)

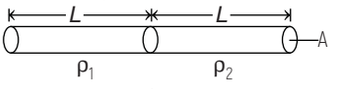
It is clear from Eq. (i), when area increases the current density decreases so the number of flow of electrons will be same and thus the current will be constant.

15 Two metal wires of identical dimensions are connected in series. If σ_1 and σ_2 are the conductivities of the metal wires respectively, the effective conductivity of the combination is **[CBSE AIPMT 2015]**

(a) $\frac{2\,\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$ (b) $\frac{\sigma_1 + \sigma_2}{2\,\sigma_1 \sigma_2}$
(c) $\frac{\sigma_1 + \sigma_2}{\sigma_1 \sigma_2}$ (d) $\frac{\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$

Ans. *(a)*

Net resistance of a metal wire having resistivity ρ, we have



$$R_1 = \rho_1 \frac{L}{A}$$

Similarly, $R_2 = \rho_2 \frac{L}{A}$

Then, net effective resistance of two metal wires,

$$R_{eq} = R_1 + R_2 \;\Rightarrow\; \rho \frac{2L}{A} = \rho_1 \frac{L}{A} + \rho_2 \frac{L}{A}$$

$$\Rightarrow \quad 2\rho = \rho_1 + \rho_2$$

As, conductivity $\sigma = \frac{1}{\rho}$, we have

$$\frac{2}{\sigma} = \frac{1}{\sigma_1} + \frac{1}{\sigma_2} \;\Rightarrow\; \frac{2}{\sigma} = \frac{\sigma_1 + \sigma_2}{\sigma_1 \sigma_2}$$

$\Rightarrow$ Net effective conductivity of combined wires,

$$\sigma = \frac{2\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$$

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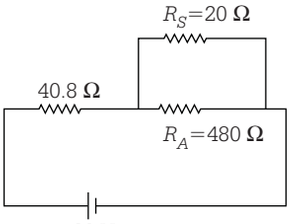
16 A circuit contains an ammeter, a battery of 30 V and a resistance 40.8 Ω all connected in series. If the ammeter has a coil of resistance 480 Ω and a shunt of 20 Ω, then reading in the ammeter will be **[CBSE AIPMT 2015]**

(a) 0.5 A (b) 0.25 A
(c) 2 A (d) 1 A

Ans. *(a)*

Effective resistance of a circuit,



$$R_{\text{eff}} = 40.8 + \frac{480 \times 20}{480 + 20}$$

$$= 40.8 + 19.2 = 60\ \Omega$$

So, current flowing across ammeter,

$$I = \frac{V}{R} = \frac{30}{60} = \frac{1}{2} = 0.5\ \text{A}$$

Hence, reading of ammeter = 0.5 A

17 A wire of resistance 4Ω is stretched to twice its original length. The resistance of stretched wire would be **[NEET 2013]**

(a) 2 Ω (b) 4 Ω (c) 8 Ω (d) 16 Ω

Ans. *(d)*

As the resistance of stretched wire to length n times of original length is

$R' = n^2 R = 2^2 \times 4 = 4 \times 4 = 16\ \Omega$

where, R = original resistance

R' = final resistance

18 The mean free path of electrons in a metal is 4×10^{-8} m. The electric field which can give on an average 2 eV energy to an electron in the metal will be in unit of $\mathbf{Vm^{-1}}$ **[CBSE AIPMT 2009]**

(a) 8×10^7 (b) 5×10^{-11}
(c) 8×10^{-11} (d) 5×10^7

Ans. *(d)*

Energy = 2eV

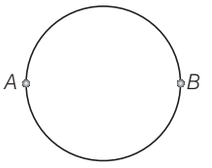
$eV_0 = 2\text{eV} \Rightarrow V_0 = 2$

So, electric field, $\mathbf{E} = \dfrac{2}{4 \times 10^{-8}}$

$= 0.5 \times 10^8$

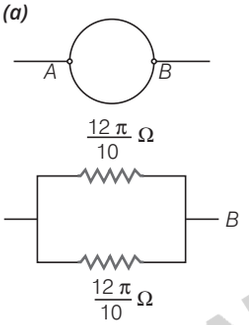
$= 5 \times 10^7$ V/m

19 A wire of resistance 12 Ω m^{-1} is bent to form a complete circle of radius 10 cm. The resistance between its two diametrically opposite points A and B as shown in the figure is **[CBSE AIPMT 2009]**



(a) 0.6 π Ω (b) 3 Ω
(c) 6 π Ω (d) 6 Ω

Ans. *(a)*



Circumference of circle $= 2\pi r = 2 \times \pi \dfrac{10}{100}$

$= \dfrac{2\pi}{10} = \dfrac{\pi}{5}$

Resistance of wire $= 12 \times \dfrac{\pi}{5} = \dfrac{12\pi}{5}$

Resistance of each section $= \dfrac{12\pi}{10}\ \Omega$

∴ Equivalent resistance

$$= \frac{\frac{12\pi}{10} \times \frac{12\pi}{10}}{\frac{12\pi}{10} + \frac{12\pi}{10}}$$

$$\Rightarrow \quad = \frac{6\pi}{10} = 0.6\ \pi\ \Omega$$

20 A wire of a certain material is stretched slowly by 10 percent. Its new resistance and specific resistance become respectively **[CBSE AIPMT 2008]**

(a) 1.2 times, 1.1 times
(b) 1.21 times, same
(c) Both remain the same
(d) 1.1 times, 1.1 times

Ans. *(b)*

After stretching, specific resistance (ρ) will remain same.

Original resistance of wire, $R = \dfrac{\rho l}{A}$

Ratio of resistance before and after streching,

$$\frac{R_2}{R_1} = \frac{l_2}{l_1} \times \frac{A_1}{A_2} = \left[\frac{l_2}{l_1}\right]^2$$

$$\frac{R_2}{R_1} = \frac{(l + 10\%l)^2}{l^2}$$

$$\frac{R_2}{R_1} = \frac{\left(\frac{11}{10} l\right)^2}{l^2}$$

$$R_2 = 1.21 R_1$$

21 When a wire of uniform cross-section a, length l and resistance R is bent into a complete circle, resistance between two of diametrically opposite points will be **[CBSE AIPMT 2005]**

(a) $\dfrac{R}{4}$ (b) $\dfrac{R}{8}$ (c) $4R$ (d) $\dfrac{R}{2}$

Ans. *(a)*

When wire is bent to form a complete circle, then

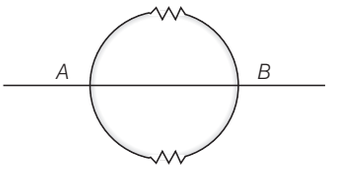
Total circumference,

$2\pi r$ = Total length, R

$$\Rightarrow \qquad r = \frac{R}{2\pi}$$

Resistance of each semicircle $= \pi r$

$$= \frac{\pi R}{2\pi} = \frac{R}{2}$$



Thus, net resistance in parallel combination of two semicircular resistances

$$R' = \frac{\frac{R}{2} \times \frac{R}{2}}{\frac{R}{2} + \frac{R}{2}} = \frac{\frac{R^2}{4}}{R} = \frac{R}{4}$$

22 n resistances each of r ohm, when connected in parallel give an equivalent resistance of R ohm. If these resistances were connected in series, the combination would have a resistance in ohms, equal to **[CBSE AIPMT 2004]**

(a) $n^2 R$ (b) $\dfrac{R}{n^2}$
(c) $\dfrac{R}{n}$ (d) nR

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Ans. *(a)*

Equivalent resistance of n resistances each of r ohm in parallel is given by

$$\frac{1}{R}=\frac{1}{r}+\frac{1}{r}+\ldots+n\text{ times}=\frac{n}{r}$$

So, $r=nR$

When these resistances are connected in series, effective resistance is

$$R'=r+r+\ldots+n\text{ times}=nr$$

$$\therefore\quad R'=n(nR)=n^2R$$

23 The electric resistance of a certain wire of iron is R. If its length and radius are both doubled, then **[CBSE AIPMT 2004]**

(a) the resistance will be doubled and the specific resistance will be halved
(b) the resistance will be halved and the specific resistance will remain unchanged
(c) the resistance will be halved and the specific resistance will be doubled
(d) the resistance and the specific resistance will both remain unchanged

Ans. *(b)*

The formula for resistance of wire is

$$R=\frac{\rho l}{A}$$

where, ρ = specific resistance of the wire

$$\Rightarrow\quad R\propto\frac{l}{A}$$

$$\Rightarrow\quad R\propto\frac{l}{r^2}\qquad(\because A=\pi r^2)$$

$$\therefore\quad \frac{R_1}{R_2}=\frac{l_1}{l_2}\times\frac{r_2^2}{r_1^2}\qquad\ldots(i)$$

Given, $l_1=l, l_2=2l, r_1=r, r_2=2r, R_1=R$.

Substituting these values in Eq. (i), we have

$$\frac{R_1}{R_2}=\frac{l}{2l}\times\frac{(2r)^2}{r^2}$$

$$\frac{R_1}{R_2}=\frac{l}{2l}\times\frac{(2r)^2}{r^2}$$

$$\frac{R_1}{R_2}=2\Rightarrow R_2=\frac{R}{2}$$

Therefore, resistance will be halved.

Now, the specific resistance of the wire does not depend on the geometry of the wire. Hence, it remains unchanged.

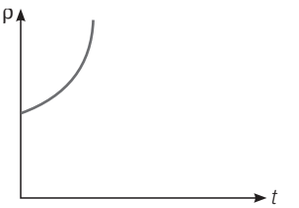
24 The specific resistance of a conductor increases with **[CBSE AIPMT 2002]**

(a) increase in temperature
(b) increase in cross-sectional area
(c) decrease in length
(d) decrease in cross-sectional area

Ans. *(a)*

The specific resistance (resistivity) of a metallic conductor nearly increases with increasing temperature as shown in figure. This is because, with the increase in temperature the ions of the conductors vibrate with greater amplitude and the collisions between electrons and ions become more frequent, over a small temperature range (upto 100°C). The resistivity of a metal can be represented approximately by the equation

$$\rho_t=\rho_0(1+\alpha t)$$



The factor α is called the temperature coefficient of resistivity.

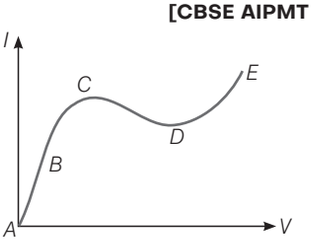
25 The resistance of a discharge tube is **[CBSE AIPMT 1999]**

(a) zero (b) ohmic
(c) non-ohmic (d) infinity

Ans. *(c)*

In discharge tube, the current is due to flow of positive ions and electrons. Moreover, secondary emission of electrons is also possible. So, V-I curve is non-linear, hence its resistance is non-ohmic.

26 From the graph between current I and voltage V shown in figure, identify the portion corresponding to negative resistance. **[CBSE AIPMT 1997]**



(a) DE (b) CD
(c) BC (d) AB

Ans. *(b)*

From Ohm's law, resistance $R=\frac{\Delta V}{\Delta I}$

Resistance is said to be negative if on increasing voltage or temperature, current decreases.

In V-I graph, for portion CD of graph, the current decreases with increasing voltage.

Thus, portion CD corresponds to negative resistance.

Alternative

We know that the slope of graph V-I will give the resistance, since slope of CD curve is negative.

So, it has negative resistance.

27 There are three copper wires of length and cross-sectional area (L, A), $(2L, A/2)$ $(L/2, 2A)$. In which case is the resistance minimum ? **[CBSE AIPMT 1997]**

(a) It is the same in all three cases
(b) Wire of cross-sectional area $2A$
(c) Wire of cross-sectional area A
(d) Wire of cross-sectional area $\frac{1}{2}A$

Ans. *(b)*

The relation between length and area is

$$R=\frac{\rho l}{A}\qquad\ldots(i)$$

where, ρ being specific resistance is the proportionality constant and depends on nature of material.

(i) Length $=\frac{L}{2}$, area $=2A$

Putting in Eq. (i), we have

$$R=\frac{\rho(L/2)}{2A}=\frac{\rho L}{4A}$$

(ii) Length $=L$, area $=A$

Putting in Eq. (i), we have

$$R=\frac{\rho L}{A}$$

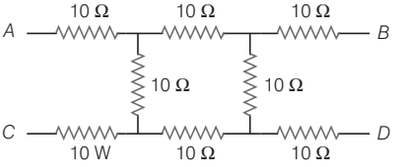
(iii) Length $=2L$, area $=\frac{A}{2}$

Putting in Eq. (i), we have

$$R=\rho\frac{2L}{A/2}=\frac{4\rho L}{A}$$

As it is understood from above, resistance is minimum only in option (b).

28 What will be the equivalent resistance of circuit shown in figure between two points A and D ? **[CBSE AIPMT 1996]**



(a) 10 Ω (b) 20 Ω (c) 30 Ω (d) 40 Ω

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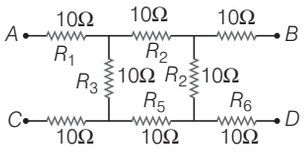
Ans. *(c)*



Effective resistance of R_2 and R_4 in series,

$$R' = 10 + 10 = 20\ \Omega$$

Effective resistance of R_3 and R_5 in series,

$$R'' = 10 + 10 = 20\ \Omega$$

Net total resistance of R' and R'' in parallel is

$$R_p = \frac{20 \times 20}{20 + 20} = 10\ \Omega$$

$\therefore$ Total resistance between A and D

$$= 10 + 10 + 10$$
$$= 30\ \Omega$$

29 If a neglegibly small current is passed through a wire of length 15 m and of resistance 5 Ω having uniform cross-section of 6×10^{-7} m^2, then coefficient of resistivity of material, is **[CBSE AIPMT 1996]**

(a) 1×10^{-7} Ω-m (b) 2×10^{-7} Ω-m
(c) 3×10^{-7} Ω-m (d) 4×10^{-7} Ω-m

Ans. *(b)*

Resistance of a given conducting wire is given by

$$R = \rho \cdot \frac{l}{A}$$

where, ρ is the specific resistance of the material of the conductor.

Here, $l = 15$ m
$A = 6 \times 10^{-7}$ m^2
$R = 5\ \Omega$, $\rho = ?$

$\therefore$ $$\rho = \frac{RA}{l}$$
$$= \frac{5 \times 6 \times 10^{-7}}{15}$$
$$= 2 \times 10^{-7}\ \Omega\text{-m}$$

30 If the resistance of a conductor is 5 Ω at 50°C and 7 Ω at 100°C, then the mean temperature coefficient of resistance (of the material) is **[CBSE AIPMT 1996]**

(a) 0.01/°C (b) 0.04/°C
(c) 0.06/°C (d) 0.08/°C.

Ans. *(a)*

Temperature coefficient of resistance is defined as the increase in resistance per unit original resistance per degree rise of temperature and is given by

$$\alpha = \frac{R_t - R_o}{R_o \times t} \quad \text{or} \quad R_t = R_o\,(1 + \alpha t)$$

R_t = Resistance at final temperature
R_o = Resistance at initial temperature
t = Change in temperature

Case **I** $5 = R_o\,[1 + \alpha(50)]$ ...(i)
Case **II** $7 = R_o\,[1 + \alpha(100)]$ ...(ii)

Dividing Eq. (i) by Eq. (ii)

$$\frac{5}{7} = \frac{1 + 50\alpha}{1 + 100\alpha}$$

$\therefore$ $5 + 500\alpha = 7 + 350\alpha$

$\therefore$ $$\alpha = \frac{2}{150} = 0.01/°C$$

31 If a wire of resistance R is melted and recasted to half of its length, then the new resistance of the wire will be **[CBSE AIPMT 1995]**

(a) $\frac{R}{4}$ (b) $\frac{R}{2}$
(c) R (d) $2R$

Ans. *(a)*

Let initial resistance of wire be R, its initial length is l_1 and final length is l_2. According to problem $l_2 = 0.5\,l_1$, volume of the wire is $= lA$.

Since, the volume of wire remains the same after recasting, therefore

$$l_1 A_1 = l_2 A_2$$

$\therefore$ $$\frac{l_1}{l_2} = \frac{A_2}{A_1} \quad \text{or} \quad \frac{l_1}{0.5\,l_1} = \frac{A_2}{A_1}$$

$\therefore$ $$\frac{A_2}{A_1} = 2$$

As resistance of wire, $R \propto \frac{l}{A}$

$\therefore$ $$\frac{R_1}{R_2} = \frac{l_1}{l_2} \times \frac{A_2}{A_1} = \frac{l_1}{0.5\,l_1} \times 2 = 4$$

or $$R_2 = \frac{R_1}{4} = \frac{R}{4}$$

Note

As we know the resistance R of wire of length l and area of cross-section, A is given by $R = \int l/A$

32 Two wires of the same metal have same length, but their cross-sections are in the ratio 3 : 1. They are joined in series. The resistance of thicker wire is 10 Ω. The total resistance of the combination will be **[CBSE AIPMT 1995]**

(a) 10 Ω (b) 20 Ω
(c) 40 Ω (d) 100 Ω

Ans. *(c)*

For the same length and same material,

$$\frac{R_2}{R_1} = \frac{A_1}{A_2} = \frac{3}{1}$$

or $$R_2 = 3R_1$$

The resistance of thick wire,

$$R_1 = 10\ \Omega$$

The resistance of thin wire

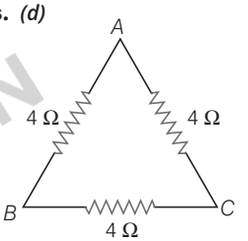
$$= 3R_1 = 3 \times 10 = 30\ \Omega$$

Total resistance $= 10 + 30 = 40\ \Omega$

33 Three resistances each of 4 Ω are connected to form a triangle. The resistance between any two terminals is **[CBSE AIPMT 1993]**

(a) 12 Ω (b) 2 Ω
(c) 6 Ω (d) $\frac{8}{3}$ Ω

Ans. *(d)*



Between any two terminals, two resistors of two arms are in series i.e. between B and C, equivalent resistance is

$$\frac{1}{R_{BC}} = \frac{1}{4} + \frac{1}{8}$$
$$\frac{1}{R_{BC}} = \frac{2+1}{8}$$

$\therefore$ $$R_{BC} = \frac{8}{3}\ \Omega$$

34 The velocity of charge carriers of current (about 1 A) in a metal under normal conditions is of the order of **[CBSE AIPMT 1991]**

(a) a fraction of mm/s
(b) velocity of light
(c) several thousand m/s
(d) a few hundred m/s

Ans. *(a)*

The charged particles whose flow in a definite direction constitutes the electric current are called current carriers. In metals the valence electrons of the atoms do not remain attached to individual atoms but are free to move throughout the volume of the conductor. Their velocity under normal conditions is of the order of a fraction of mm/s.

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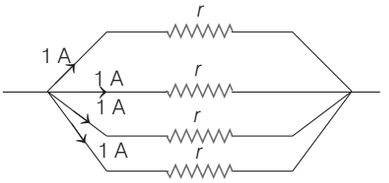
35 You are given several identical resistances each of value $R = 10\,\Omega$ and each capable of carrying a maximum current of 1A. It is required to make a suitable combination of these resistances of $5\,\Omega$ which can carry a current of 4 A. The minimum number of resistances of the type R that will be required for this job is **[CBSE AIPMT 1990]**

(a) 4 (b) 10
(c) 8 (d) 20

Ans. *(c)*



To carry a current of 4 A we need four path, each carrying a current of 1A. Let r be the resistance of each path. These resistances are connected in parallel. So, their equivalent resistance.

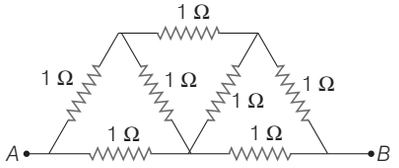
$$\frac{1}{r_p} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r} \quad \text{or} \quad r_p = \frac{r}{4}.$$

But, $r_p = \frac{r}{4} = 5$ (given)

$\therefore \quad r = 20\,\Omega$

For this purpose two resistances should be connected is series. There are four such combinations in parallel. Hence, the total number of resistances $= 4 \times 2 = 8$.

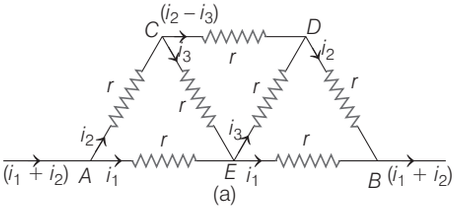
36 In the network shown in figure each resistance is $1\,\Omega$. The effective resistance between A and B is **[CBSE AIPMT 1990]**



(a) $\frac{4}{3}\,\Omega$ (b) $\frac{3}{2}\,\Omega$
(c) $7\,\Omega$ (d) $\frac{8}{7}\,\Omega$

Ans. *(d)*

The distribution of currents in the circuit is shown in the Fig. (a). Due to symmetry, current in arm AE is equal to current in the arm EB. Since, current in the arm CE is equal to the current in the arm ED, therefore the resistance of network will not change, if the wires CED and AEB are disconnected at E, as shown in Fig. (b).



(a)

Now, resistance of path $AEB = r + r = 2r$

Resistance of path

$$ACDB = r + \frac{(2r) \times r}{(2r) + r} + r = \frac{8r}{3}$$

The paths AEB and $ACDB$ are in parallel, therefore the effective resistance between A and B will be

$$\frac{1}{R} = \frac{1}{2r} + \frac{3}{8r} = \frac{4+3}{8r} = \frac{7}{8r}$$

or $\quad R = \frac{8r}{7}$

But $\quad r = 1\,\Omega,$

Therefore, $\quad R = \frac{8 \times 1}{7} = \frac{8}{7}\,\Omega$

37 n equal resistors are first connected in series and then connected in parallel. What is the ratio of the maximum to the minimum resistance ? **[CBSE AIPMT 1989]**

(a) n (b) $1/n^2$ (c) n^2 (d) $1/n$

Ans. *(c)*

When resistors are connected in series, then effective resistance of series combination

$$R_S = R + R + \ldots + n \text{ terms} = nR \quad \ldots(i)$$

When resistors are connected in parallel, then effective resistance

$$\frac{1}{R_P} = \frac{1}{R} + \frac{1}{R} + \ldots + n \text{ terms}$$

or $\quad \frac{1}{R_P} = \frac{n}{R} \quad \ldots(ii)$

$$R_p = \frac{R}{n}$$

From Eqs. (i) and (ii), we get

$$\frac{R_S}{R_P} = \frac{n^2}{1}$$

38 The masses of the three wires of copper are in the ratio of 1:3:5 and their lengths are in the ratio of 5:3:1. The ratio of their electrical resistance is **[CBSE AIPMT 1988]**

(a) 1:3:5 (b) 5:3:1
(c) 1:25:125 (d) 125:15:1

Ans. *(d)*

Let A_1, A_2, A_3 be the area of cross-section of three wires of copper of masses m_1, m_2, m_3 and length l_1, l_2, l_3 respectively. Given $m_1 = m, m_2 = 3m, m_3 = 5m, l_1 = 5l, l_2 = 3l, l_3 = l$

Mass = volume × density,

So, $\quad m = A_1 \times 5l \times \rho \quad \ldots(i)$

$3m = A_2 \times 3l \times \rho \quad \ldots(ii)$

$5m = A_3 \times l \times \rho \quad \ldots(iii)$

From Eqs. (i) and (ii), we get

$$A_2 = 5A_1$$

From Eqs. (i) and (iii),

$$A_3 = 25A_1$$

$$\therefore \quad R_1 = \rho \frac{l_1}{A_1} = \rho \frac{5l}{A_1}$$

$$R_2 = \rho \frac{l_2}{A_2} = \rho \times \frac{3l}{5A_1} = \frac{3}{25} R_1$$

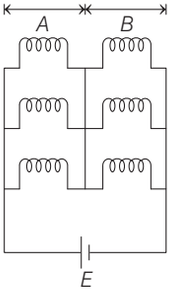
$$R_3 = \rho \frac{l_3}{A_3} = \frac{\rho \times l}{25 A_1} = \frac{R_1}{125}$$

$$\therefore R_1 : R_2 : R_3 = R_1 : \frac{3}{25} R_1 : \frac{R_1}{125}$$

$$= 125 : 15 : 1$$

TOPIC 2
Heating Effect of Current

39 Six similar bulbs are connected as shown in the figure with a DC source of emf E and zero internal resistance.
The ratio of power consumption by the bulbs when (i) all are glowing and (ii) in the situation when two from section A and one from section B are glowing, will be **[NEET (National) 2019]**



(a) 9 : 4 (b) 1 : 2
(c) 2 : 1 (d) 4 : 9

Ans. *(a)*

Case I When all bulbs are glowing, then the circuit can be realised as shown in the figure below.

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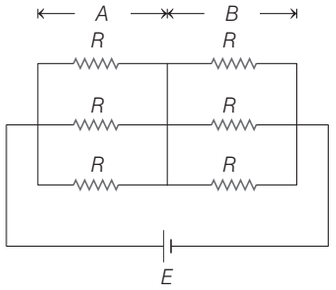


∴ The equivalent resistance of this circuit is

$$R_{eq} = R_A + R_B$$

As, section A has three parallel resistance, so equivalent resistance,

$$R_A = \frac{R}{3}$$

Similarly, for section B, equivalent resistance,

$$R_B = \frac{R}{3}$$

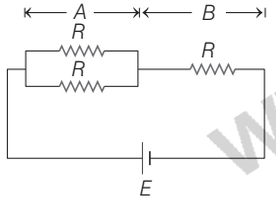
$$\therefore \quad R_{eq} = \frac{R}{3} + \frac{R}{3} = \frac{2R}{3} \quad \text{... (i)}$$

Thus, power consumed in this circuit,

$$P_1 = \frac{V^2}{R} = \frac{E^2}{R_{eq}} = \frac{3E^2}{2R} \text{ [using Eq. (i)]}$$

...(ii)

Case II When two from section A and one from section B glow, the circuit can be realised as shown in the figure below.



∴ Equivalent resistance of section A,

$$R_A = \frac{R}{2}$$

and of section B,

$$R_B = R$$

Thus, equivalent resistance of the entire circuit becomes

$$R_{eq} = R_A + R_B = \frac{R}{2} + R = \frac{3R}{2} \quad \text{... (iii)}$$

∴ Power consumed by this circuit,

$$P_2 = \frac{V^2}{R} = \frac{E^2}{R_{eq}} = \frac{2E^2}{3R}$$

[using Eq. (iii)]... (iv)

So, ratio of power of two cases is obtained from Eqs. (ii) and (iv), we get

$$\frac{P_1}{P_2} = \frac{3E^2}{2R} \times \frac{3R}{2E^2} = \frac{9}{4} \text{ or } 9:4$$

40 The charge following through a resistance R varies with time t as $Q = at - bt^2$, where a and b are positive constants. The total heat produced in R is **[NEET 2016]**

(a) $\frac{a^3R}{3b}$ (b) $\frac{a^3R}{2b}$ (c) $\frac{a^3R}{b}$ (d) $\frac{a^3R}{6b}$

Ans. *(d)*

Given, charge $Q = at - bt^2$ ...(i)

∵ We know that current, $I = \frac{d\theta}{dt}$

So, eq. (i) can be written as

$$I = \frac{d}{dt}(at - bt^2) \Rightarrow I = a - 2bt \quad \text{...(ii)}$$

For maximum value of t, till the current exist is given by

$$\Rightarrow \quad a - 2bt = 0$$

$$\therefore \quad t = \frac{a}{2b} \quad \text{...(iii)}$$

∵ The total heat produced (H) can be given as

$$H = \int_0^t I^2 R\, dt$$

$$= \int_0^{a/2b} (a - 2bt)^2 \, R \, . dt \qquad \left\{\because t = \frac{a}{2b}\right\}$$

$$= \int_0^{a/2b} (a^2 + 4b^2t^2 - 4abt)\, R dt$$

$$H = \left[a^2t + 4b^2\,\frac{t^3}{3} - \frac{4abt^2}{2}\right]_0^{a/2b} R$$

Solving above equation, we get

$$\Rightarrow \quad H = \frac{a^3R}{6b}$$

41 A filament bulb (500 W, 100 V) is to be used in a 230 V main supply. When a resistance R is connected in series, it works perfectly and the bulb consumes 500 W. The value of R is **[NEET 2016]**

(a) 230 Ω (b) 46 Ω
(c) 26 Ω (d) 13 Ω

Ans. *(c)*

If a rated voltage and power are given,

then $P_{rated} = \frac{V^2_{rated}}{R}$

∴ Current in the bulb, $i = \frac{P}{V}$ (∵ $P = Vi$)

$$i = \frac{500}{100} = 5 \text{ A}$$

∴ Resistance of bulb,

$$R_b = \frac{100 \times 100}{500} = 20\ \Omega$$

∵ Resistance R is connected in series.

$$\therefore \quad \text{Current, } i = \frac{E}{R_{net}} = \frac{230}{R + R_b}$$

$$\Rightarrow \quad R + 20 = \frac{230}{5} = 46$$

$$\therefore \quad R = 26\ \Omega$$

42 Two cities are 150 km apart. Electric power is sent from one city to another city through copper wires. The fall of potential per km is 8 V and the average resistance per km is 0.5 Ω. The power loss in the wire is **[CBSE AIPMT 2014]**

(a) 19.2 W (b) 19.2 kW
(c) 19.2 J (d) 12.2 kW

Ans. *(b)*

Potential drop between two cities is

$$= 150 \times 8 = 1200 \text{ V}$$

Average resistance of total wire

$$= 0.5 \times 150 = 75\ \Omega$$

So, power loss $P = \frac{V^2}{R}$

$$= \frac{1200 \times 1200}{75} = 19200 \text{ W}$$

$$= 19.2 \text{ kW}$$

43 If voltage across a bulb rated 220 V-100 W drops by 2.5% of its rated value, the percentage of the rated value by which the power would decrease is **[CBSE AIPMT 2012]**

(a) 20% (b) 2.5%
(c) 5% (d) 10%

Ans. *(c)*

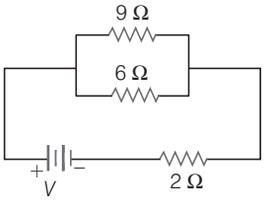
Power, $(P) = \frac{V^2}{R}$

For small variation,

$$\frac{\Delta P}{P} \times 100 = 2 \times \frac{\Delta V}{V} \times 100 = 2 \times 2.5 = 5\%$$

Therefore, power would decrease by 5%.

44 If power dissipated in the 9 Ω resistor in the circuit shown is 36W, the potential difference across the 2 Ω resistor is **[CBSE AIPMT 2011]**



(a) 8 V (b) 10 V (c) 2 V (d) 4 V

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Ans. *(b)*

Electric power, $P = i^2 R$

$\therefore$ Current, $i = \sqrt{\frac{P}{R}}$

For resistance of 9 Ω,

$$i_1 = \sqrt{\frac{36}{9}} = \sqrt{4} = 2\text{ A}$$

$$i_2 = \frac{i_1 \times R}{6} = \frac{2 \times 9}{6} = 3\text{ A}$$

$$I = i_1 + i_2 = 2 + 3 = 5\text{ A}$$

So, $V_2 = IR_2 = 5 \times 2 = 10\text{ V}$

45 An electric kettle takes 4 A current at 220 V. How much time will it take to boil 1 kg of water from temperature 20°C?

[CBSE AIPMT 2008]

(a) 6.3 min (b) 8.4 min
(c) 12.6 min
(d) 4.2 min

Ans. *(a)*

$$Vit = ms\,\Delta t$$

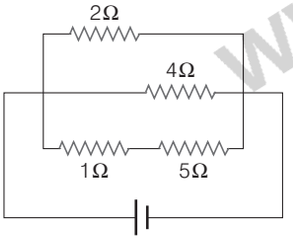
$$\Rightarrow \quad t = \frac{ms\,\Delta t}{Vi}$$

$$= \frac{1 \times 4200 \times 80}{220 \times 4}$$

$$= 381.82\text{ s}$$

$$= 6.3\text{ min}$$

46 A current of 3 A flows through the 2 Ω resistor shown in the circuit. The power dissipated in the 5 Ω resistor is **[CBSE AIPMT 2008]**



(a) 4 W (b) 2 W
(c) 1 W (d) 5 W

Ans. *(d)*

Voltage across 2 Ω,

$= 3 \times 2 = 6\text{ V}$

Voltage across 4 Ω and (5 Ω + 1 Ω) resistor is same.

So, current across $5\,\Omega = \frac{6}{1+5} = 1\text{ A}$

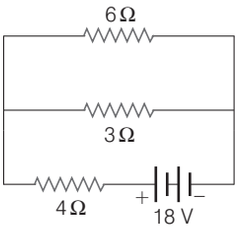
$\left[i = \frac{V}{R}\right]$

Power across $5\,\Omega = P = i^2 R$

$= (1)^2 \times 5$

$= 5\text{ W}$

47 The total power dissipated in watts in the circuit shown here is **[CBSE AIPMT 2007]**



(a) 16 (b) 40 (c) 54 (d) 4

Ans. *(c)*

The resistance of 6 Ω and 3 Ω are in parallel in the given circuit, their equivalent resistance is

$$\frac{1}{R_1} = \frac{1}{6} + \frac{1}{3} = \frac{1+2}{6} = \frac{1}{2} \quad \text{or} \quad R_1 = 2\,\Omega$$

Again, R_1 is in series with 4 Ω resistance, hence

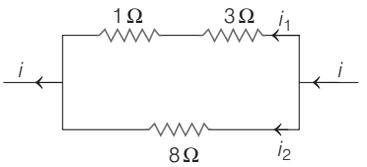
$$R = R_1 + 4 = 2 + 4 = 6\,\Omega$$

Thus, the total power dissipated in the circuit

$P = \frac{V^2}{R}$; Here, $V = 18$ V, $R = 6\,\Omega$

Thus, $P = \frac{(18)^2}{6} = 54\text{ W}$

48 Power dissipated across the 8 Ω resistor in the circuit shown here is 2 W. The power dissipated in watt units across the 3 Ω resistor is **[CBSE AIPMT 2006]**



(a) 2.0 (b) 1.0 (c) 0.5 (d) 3.0

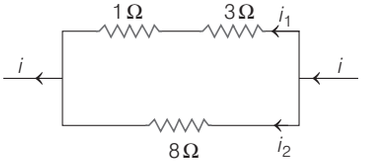
Ans. *(d)*

Problem Solving Strategy Find the equivalent resistance of the circuit and then calculate the power dissipated by the circuit.

Resistances 1 Ω and 3 Ω are connected in series, so, effective resistance

$R' = 1 + 3 = 4\,\Omega$

Now, R' and 8 Ω are in parallel. We know that potential difference across resistances in parallel is same.



So, from Kirchhoff's law, $V_1 = V_2$

$R' \times i_1 = 8i_2$ or $4 \times i_1 = 8i_2$

or $i_1 = \frac{8}{4} i_2 = 2i_2$

or $i_1 = 2i_2$ ...(i)

Power dissipated across 8 Ω resistance is

$i_2^2\,(8)\,t = 2\text{ W}$ $[\because P = iRt]$

or $i_2^2 t = \frac{2}{8} = 0.25\text{ W}$ ...(ii)

Power dissipated across 3 Ω resistance is

$H = i_1^2\,(3)\,t$

$= (2i_2)^2\,(3)\,t = 12\,i_2^2\,t$

but $i_2^2\,t = 0.25$ W

$H = 12 \times 0.25 = 3\text{ W}$

49 A 5 A fuse wire can withstand a maximum power of 1 W in circuit. The resistance of the fuse wire is **[CBSE AIPMT 2005]**

(a) 0.2 Ω (b) 5 Ω
(c) 0.4 Ω (d) 0.04 Ω

Ans. *(d)*

As we know that,

Power $P = i^2 R$

$\left[\begin{array}{l}\text{where, } i = \text{current in circuit} \\ R = \text{resistance}\end{array}\right]$

$R = \frac{p}{i^2}$

Given, $P = 1\text{ W}$, $i = 5\text{ A}$

$R = \frac{1}{(5)^2} = 0.04\,\Omega$

50 In India, electricity is supplied for domestic use at 220 V. It is supplied at 110 V in USA. If the resistance of a 60 W bulb for use in India is R, the resistance of a 60 W bulb for use in USA will be **[CBSE AIPMT 2004]**

(a) R (b) $2R$ (c) $\frac{R}{4}$ (d) $\frac{R}{2}$

Ans. *(c)*

Since, power rating of bulb in both the countries India and USA is same, so

$$\frac{V_1^2}{R_1} = \frac{V_2^2}{R_2} \qquad \left[P = \frac{V^2}{R}\right]$$

$$\Rightarrow \quad \frac{220 \times 220}{R_1} = \frac{110 \times 110}{R_2}$$

$$\Rightarrow \quad \frac{R_2}{R_1} = \frac{110 \times 110}{220 \times 220}$$

$$\Rightarrow \quad R_2 = \frac{R}{4} \qquad (\because R_1 = R)$$

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51 When three identical bulbs of 60 W, 200 V rating are connected in series to a 200 V supply, the power drawn by them will be

[CBSE AIPMT 2004]

(a) 60 W (b) 180 W (c) 10 W (d) 20 W

Ans. *(d)*

Let R_1, R_2 and R_3 are the resistances of three bulbs respectively.

In series order,

$$R = R_1 + R_2 + R_3$$

but, $R = \frac{V^2}{P}$ and supply voltage in series order is the same as the rated voltage.

$$\therefore \quad \frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$$

$$\text{or} \quad \frac{1}{P} = \frac{1}{60} + \frac{1}{60} + \frac{1}{60}$$

$$\text{or} \quad P = \frac{60}{3} = 20 \text{ W}$$

Alternative

As three bulbs have same power and voltage so, they have equal resistance. So, power equivalent when connected in series is given by,

$$\frac{1}{P_{E0}} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}$$

$$\frac{1}{P_{E0}} = \frac{1}{P} + \frac{1}{P} + \frac{1}{P} \quad (\text{as } P_1 = P_2 = P_3 = P)$$

$$\text{So, } P_{E0} = \frac{P}{3} \Rightarrow \frac{60}{3} = 20 \text{ W}$$

52 Two 220 V, 100 W bulbs are connected first in series and then in parallel. Each time the combination is connected to a 220 V AC supply line. The power drawn by the combination in each case respectively will be

[CBSE AIPMT 2003]

(a) 200 W, 150 W (b) 50 W, 200 W
(c) 50 W, 100 W (d) 100 W, 50 W

Ans. *(b)*

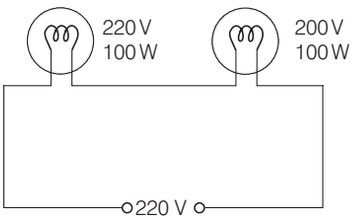
Power $P = 100$ W, Voltage, $V = 220$ V

$$P = \frac{V^2}{R}$$

$$\therefore \quad R = \frac{V^2}{P} = \frac{(220)^2}{100} = \frac{220 \times 220}{100} \ \Omega$$

As both the bulb have same voltage and power so, resistance of bulbs will also be same.

Case I When two bulbs are connected in series.



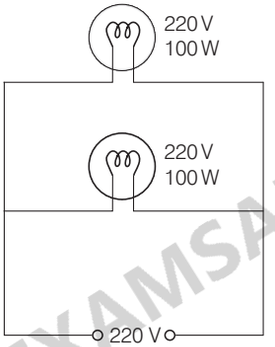
In series, $R_{eq} = R_1 + R_2$

$$= \left(\frac{220 \times 220}{100}\right) \times 2$$

Hence, $P_{eq} = \frac{V^2}{R_{eq}} = \frac{220 \times 220}{\left(\frac{220 \times 220}{100} \times 2\right)}$

$$= \frac{100}{2} = 50 \text{ W}$$

Case II When two bulbs are connected in parallel.



In parallel, $R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$

$$= \frac{\left(\frac{220 \times 220}{100}\right)^2}{\frac{220 \times 220}{100} \times 2}$$

$$R_{eq} = \frac{220 \times 220}{100} \times \frac{1}{2}$$

Hence, $P_{eq} = \frac{V^2}{R_{eq}} = \frac{220 \times 220}{\frac{220 \times 220}{100} \times \frac{1}{2}}$

$$= 200 \text{ W}$$

Alternative

For series, $P_{eq} = \frac{P_1 P_2}{P_1 + P_2}$

$$= \frac{100 \times 100}{200} = 50 \text{ W}$$

For parallel, $P_{eq} = P_1 + P_2$

$$= 100 + 100 = 200 \text{ W}$$

Note Power equivalent of two or more resistance in series is given by $\frac{1}{P_{eq}} = \frac{1}{P_1} + \frac{1}{P_2}$ and for parallel combination $P_{eq} = P_1 + P_2$

53 An electric kettle has two heating coils. When one of the coils is connected to an AC source, the water in the kettle boils in 10 min. When the other coil is used the water boils in 40 min. If both the coils are connected in parallel, the time taken by the same quantity of water to boil will be

[CBSE AIPMT 2003]

(a) 25 min (b) 15 min
(c) 8 min (d) 4 min

Ans. *(c)*

Let R_1 and R_2 be the resistances of the coils, V be the supply voltage, H be the heat required to boil the water.

For first coil, $H = \frac{V^2 t_1}{R_1}$ ...(i)

For second coil, $H = \frac{V^2 t_2}{R_2}$ ...(ii)

Equating Eqs. (i) and (ii), we get

$$\frac{t_1}{R_1} = \frac{t_2}{R_2}$$

i.e. $\frac{R_2}{R_1} = \frac{t_2}{t_1} = \frac{40}{10} = 4 \quad \begin{bmatrix} t_1 = 10 \text{ min} \\ t_2 = 40 \text{ min} \end{bmatrix}$

$$\Rightarrow \quad R_2 = 4R_1 \quad \text{...(iii)}$$

When the two heating coils are in parallel, equivalent resistance is given by

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{R_1 \times 4R_1}{R_1 + 4R_1} = \frac{4R_1}{5}$$

and $H = \frac{V^2 t}{R}$ ...(iv)

Comparing Eqs. (i) and (iv), we get

$$\frac{V^2 t_1}{R_1} = \frac{V^2 t}{R}$$

$$\Rightarrow \quad t = \frac{R}{R_1} \times t_1 \qquad [t_1 = 10 \text{ min}]$$

$$\therefore \quad t = \frac{4}{5} \times 10 = 8 \text{ min}$$

54 Fuse wire is a wire of

[CBSE AIPMT 2003]

(a) low resistance and low melting point
(b) low resistance and high melting point
(c) high resistance and high melting point
(d) high resistance and low melting point

Ans. *(d)*

The electric fuse is a device which is used to limit the current in an electric circuit. Thus, the use of fuse

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safeguards the circuit and the appliances connected in the circuit from being damaged. It is always connected with the live (or phase) wire. The fuse wire is a short piece of wire made of a material of high resistance and low melting point so that it may easily melt due to overheating when excessive current passes through it.

55 Two bulbs 25 W, 220 V and 100 W, 220 V are given. Which has higher resistance? **[CBSE AIPMT 2000]**

(a) 25 W bulb
(b) 100 W bulb
(c) Both bulbs will have equal resistance
(d) Resistance of bulbs cannot be compared

Ans. *(a)*

Power of electric bulb, $P = \frac{V^2}{R}$

So, resistance of electric bulb, $R = \frac{V^2}{P}$

Given, $P_1 = 25$ W, $P_2 = 100$ W,
$V_1 = V_2 = 220$ V

Therefore, for same potential difference V,

$$R \propto \frac{1}{P}$$

Thus, we observe that for minimum power, resistance will be maximum and *vice-versa*.

Hence, resistance of 25 W bulb is maximum and 100 W bulb is minimum.

56 A 5°C rise in temperature is observed in a conductor by passing a current. When the current is doubled the rise in temperature will be approximately **[CBSE AIPMT 1998]**

(a) 16°C (b) 10°C (c) 20°C (d) 12°C

Ans. *(c)*

Energy loss in conductor, $Q = i^2 Rt$

where, i = current flowing through it
R = resistance of conductor
t = time for which current is passed

Heat developed = $ms\,\Delta\theta$

$\therefore \quad ms\,\Delta\theta = i^2\,Rt$

Since m, s, R, t remains constant.

So, $\Delta\theta \propto i^2$

So, for two different cases

$$\frac{\Delta\theta_2}{\Delta\theta_1} = \frac{i_2^2}{i_1^2}$$

or $$\Delta\theta_2 = \left(\frac{i_2}{i_1}\right)^2 \Delta\theta_1 \qquad \ldots(i)$$

Given, $i_2 = 2i_1$, $\Delta\theta_1 = 5°C$
So, from Eq. (i),

$$\therefore \quad \Delta\theta_2 = \left(\frac{2i_1}{i_1}\right)^2 \times 5$$
$$= 4 \times 5$$
$$= 20°C$$

57. Three equal resistors connected in series across a source of emf together dissipate 10 W of power. What will be the power dissipated in watt if the same resistors are connected in parallel across the same source of emf ? **[CBSE AIPMT 1998]**

(a) $\frac{10}{3}$ (b) 10
(c) 30 (d) 90

Ans. *(d)*

Power, $P = \frac{\Delta U}{\Delta t} = V\frac{\Delta q}{\Delta t} = Vi$

or $$P = Vi = \frac{V^2}{R} \qquad (\because V = iR)$$

When resistors are in series, then

$$R_1 = R + R + R$$
$$= 3R$$

$\therefore$ Power dissipated,

$$P_1 = \frac{V^2}{R_1} = \frac{V^2}{3R} \qquad \ldots(i)$$

When resistors are in parallel, then

$$\frac{1}{R_2} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$
$$= \frac{3}{R}$$

$\Rightarrow \quad R_2 = \frac{R}{3}$

$$\therefore \quad P_2 = \frac{V^2}{R_2} = \frac{V^2}{R/3} = \frac{3V^2}{R} \qquad \ldots(ii)$$

By taking ratio of Eqs. (i) and (ii)

$$\frac{P_2}{P_1} = \frac{3V^2}{R} \times \frac{3R}{V^2} = 9$$
$$P_2 = 9P_1$$
$$= 9 \times 10 = 90 \text{ W}$$

58. A 100 W 200 V bulb is connected to a 160 V power supply. The power consumption would be **[CBSE AIPMT 1997]**

(a) 125 W (b) 100 W
(c) 80 W (d) 64 W

Ans. *(d)*

Power consumed, $P = \frac{V^2}{R}$

and $P' = \frac{V'^2}{R}$ (As resistance is same for both the cases)

Given, $V = 200$ V
$V' = 160$ V, $P = 100$ W

Comparing two different cases of voltage supplied

So, $\frac{P'}{P} = \left(\frac{V'}{V}\right)^2$

$$= \left(\frac{160}{200}\right)^2 = (0.8)^2$$

or $P' = (0.8)^2\,P$
$= 0.64 \times 100 = 64$ W

59 A heating coil is labelled 100 W, 220 V. The coil is cut in two equal halves and the two pieces are joined in parallel to the same source. The energy now liberated per second is **[CBSE AIPMT 1995]**

(a) 25 J (b) 50 J
(c) 200 J (d) 400 J

Ans. *(d)*

When heating coil is cut into two equal parts and these parts are joined in parallel, then the resistance of the coil is reduced to $\frac{1}{4}$ of the previous value. As $\left(H \propto \frac{1}{R}\right)$, for constant voltage so, energy liberated per second becomes 4 times, i.e.

$4 \times 100 = 400$ J.

60 A 4μF conductor is charged to 400 V and then its plates are joined through a resistance of 1kΩ. The heat produced in the resistance is **[CBSE AIPMT 1994]**

(a) 0.16 J (b) 1.28 J
(c) 0.64 J (d) 0.32 J

Ans. *(d)*

The energy stored in the capacitor

$$= \frac{1}{2}CV^2.$$

This energy will be converted into heat in the resistor.

$$\therefore \quad H = \frac{1}{2}CV^2$$

where, C = capacitance of capcitor
V = voltage across the plate of capacitor

$$\Rightarrow \quad H = \frac{1}{2} \times 4 \times 10^{-6} \times (400)^2 = 0.32 \text{ J}$$

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61 40 electric bulbs are connected in series across a 220 V supply. After one bulb is fused the remaining 39 are connected again in series across the same supply. The illumination will be

[CBSE AIPMT 1989]

(a) more with 40 bulbs than with 39
(b) more with 39 bulbs than with 40
(c) equal in both the cases
(d) in the ratio $40^2 : 39^2$

Ans. *(b)*

As the voltage is same for both forty and thirty nine bulbs combination, therefore heat produced is given by $H = \frac{V^2 t}{R}$ and $H \propto \frac{1}{R}$. As equivalent resistance decreases, the combination of 39 bulbs will glow more.

62 A current of 2 A, passing through a conductor produces 80 J of heat in 10 s. The resistance of the conductor in ohm is

[CBSE AIPMT 1989]

(a) 0.5 (b) 2
(c) 4 (d) 20

Ans. *(b)*

Amount of heat produced in a conductor is equal to work done in carrying a charge q from one end of conductor to other end of conductor having potential difference V.

$\therefore \quad H = W = Vq = Vit = i^2 Rt \ [\text{as}, V = IR]$

$\therefore \quad H = i^2 Rt \text{ J}$

$\Rightarrow \quad R = \frac{H}{(i^2 t)}$

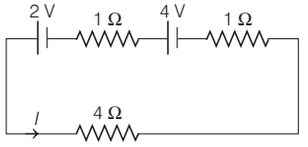
Given, $H = 80$ J, $i = 2$ A, $t = 10$ s,

So, $R = \frac{80}{(2)^2 \times 10} = 2\ \Omega$

TOPIC 3
Cells and its Combination and Kirchhoff's Rules

63 For the circuit shown in the figure, the current I will be

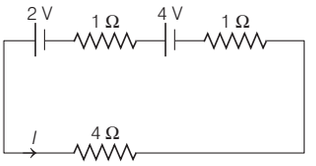
[NEET (Oct.) 2020]



(a) 0.75 A (b) 1 A
(c) 1.5 A (d) 0.5 A

Ans. *(b)*

The circuit diagram is shown below



Applying KVL in the loop, we get

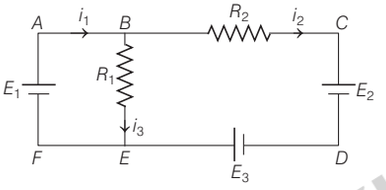
$4I + I \cdot 1 - 4 + I \cdot 1 - 2 = 0$

$\Rightarrow \quad 6I = 6$

$\Rightarrow \quad I = 1\text{A}$

64 For the circuit given below, the Kirchhoff's loop rule for the loop $BCDEB$ is given by the equation

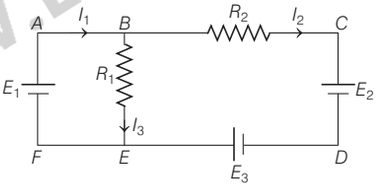
[NEET (Oct.) 2020]



(a) $-i_2 R_2 + E_2 - E_3 + i_3 R_1 = 0$
(b) $i_2 R_2 + E_2 - E_3 - i_3 R_1 = 0$
(c) $i_2 R_2 + E_2 + E_3 + i_3 R_1 = 0$
(d) $-i_2 R_2 + E_2 + E_3 + i_3 R_1 = 0$

Ans. *(b)*

The circuit diagram is given below

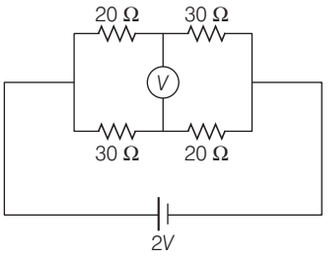


Applying KVL rule in loop $BCDEB$,

$R_2 I_2 + E_2 - E_3 - I_3 R_1 = 0$

65 The reading of an ideal voltmeter in the circuit shown is

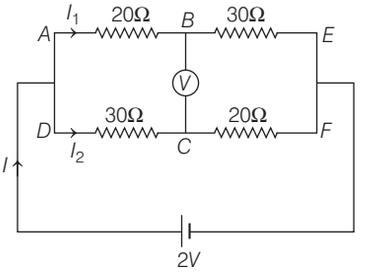
[NEET (Odisha) 2019]



(a) 0.6 V (b) 0 V
(c) 0.5 V (d) 0.4 V

Ans. *(d)*

The given circuit diagram can be drawn as shown below



The equivalent resistance of circuit is given by

$$\frac{1}{R_{eq}} = \frac{1}{R_{AE}} + \frac{1}{R_{DF}}$$
$$= \frac{1}{(20+30)} + \frac{1}{(30+20)}$$
$$= \frac{1}{50} + \frac{1}{50} = \frac{2}{50}$$

$\Rightarrow \quad R_{eq} = 25\ \Omega$

The current in circuit, $I = \frac{V}{R} = \frac{2}{25}\text{A}$

As the resistance of two branches is same i.e. 50 Ω.

So, the current $I_1 = I_2$

$\Rightarrow \quad I = I_1 + I_2$

$\frac{2}{25} = 2I_1 \ \Rightarrow \ I_2 = I_1 = \frac{1}{25}\text{A}$

$\therefore$ The voltage across AB

$$V_1 = I_1 R_1 = \frac{1}{25} \times 20$$

and voltage across CD

$$V_2 = I_2 R_2 = \frac{1}{25} \times 30$$

$\therefore$ Voltmeter reading $= V_2 - V_1$

$$= \frac{30}{25} - \frac{20}{25} = \frac{10}{25} = 0.4\text{ V}$$

66 A set of 'n' equal resistors, of value 'R' each , are connected in series to a battery of emf 'E' and internal resistance 'R'. The current drawn is I. Now, the 'n' resistors are connected in parallel to the same battery. Then, the current drawn from battery becomes $10I$. The value of 'n' is

[NEET 2018]

(a) 20 (b) 11 (c) 10 (d) 9

Ans. *(c)*

When n equal resistors of resistance R are connected in series, then the current drawn is given as

$$I = \frac{E}{nR + r}$$

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where,

nR = equivalent resistance of n resistors in series and r = internal resistance of battery.

Given, $r = R$

$$\Rightarrow \quad I = \frac{E}{nR + R} = \frac{E}{R(n+1)} \qquad ...(i)$$

Similarly, when n equal resistors are connected in parallel, then the current drawn is given as

$$I' = \frac{E}{\frac{R}{n} + R}$$

where, $\frac{R}{n}$ = equivalent resistance of n resistors in parallel.

Given, $I' = 10I$

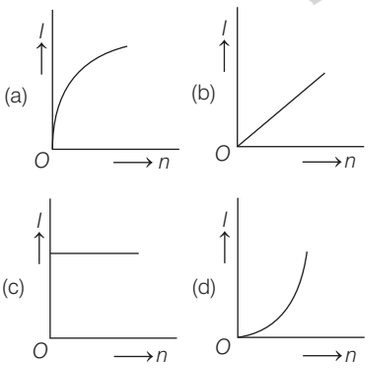
$$\Rightarrow \quad 10I = \frac{E}{\frac{R}{n} + R} = \frac{nE}{(n+1)R} \qquad ...(ii)$$

Substituting the value of I from Eq. (i) in Eq. (ii), we get

$$10\left(\frac{E}{R(n+1)}\right) = \frac{nE}{R(n+1)}$$

$$\Rightarrow \quad n = 10$$

67 A battery consists of a variable number 'n' of identical cells (having internal resistance 'r' each) which are connected in series. The terminals of the battery are short-circuited and the current I is measured. Which of the graphs shows the correct relationship between I and n? **[NEET 2018]**



Ans. ***(c)***

If n identical cells are connected in series, then

Equivalent emf of the combination,

$$E_{eq} = nE$$

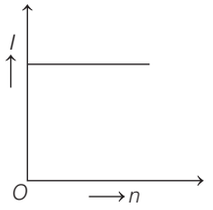
Equivalent internal resistance,

$$r_{eq} = nr$$

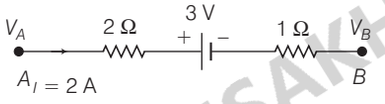
$$\therefore \text{ Current, } \quad I = \frac{E_{eq}}{r_{eq}} = \frac{nE}{nr}$$

$$\text{or} \quad I = \frac{E}{r} = \text{constant}$$

Thus, current (I) is independent of the number of cells (n) present in the circuit. Therefore, the graph showing the relationship between I and n would be as shown below.



68 The potential difference $(V_A - V_B)$ between the points A and B in the given figure is **[NEET 2016]**



(a) –3 V (b) +3 V
(c) +6 V (d) +9 V

Ans. ***(d)***

Applying KVL,

$$V_A + \Sigma V = V_B + 2 \times 2 + 2 \times 1$$

$$V_A - V_B - 3 = 4 + 2; \; V_A - V_B = 9 \text{ V}$$

69 The internal resistance of a 2.1 V cell which gives a current of 0.2 A through a resistance of 10 Ω is **[NEET 2013]**

(a) 0.2 Ω (b) 0.5 Ω
(c) 0.8 Ω (d) 1.0 Ω

Ans. ***(b)***

As, $I = \frac{E}{R + r}$

E = emf of cell

R = external resistance

r = internal resistance

I = current in circuit

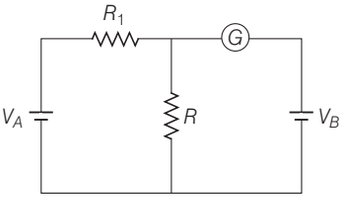
or $\quad E = I(R + r)$,

$$2.1 = 0.2(10 + r)$$

$$10 + r = \frac{2.1}{2} \times 10$$

$$\therefore \quad r = 10.5 - 10 = 0.5\ \Omega$$

70 In the circuit shown, the cells A and B have negligible resistances. For $V_A = 12$ V, $R_1 = 500\ \Omega$ and $R = 100\ \Omega$ the galvanometer (G) shows no deflection. The value of V_B is **[CBSE AIPMT 2012]**



(a) 4 V (b) 2 V
(c) 12 V (d) 6 V

Ans. ***(b)***

Concept If potential difference across $R\ \Omega$ resistor is equal to potential difference of cell B, galvanometer shows no deflection.

Applying Kirchhoff's law,

$$500I + 100I = 12$$

$$\text{So,} \quad I = \frac{12 \times 10^{-2}}{6} = 2 \times 10^{-2} \text{ A}$$

$$\text{Hence,} \quad V_B = 100(2 \times 10^{-2}) = 2 \text{ V}$$

71 A current of 2 A flows through a 2 Ω resistor when connected across a battery. The same battery supplies a current of 0.5 A when connected across a 9 Ω resistor. The internal resistance of the battery is **[CBSE AIPMT 2011]**

(a) 1/3 Ω (b) 1/4 Ω
(c) 1 Ω (d) 0.5 Ω

Ans. ***(a)***

Current in circuit connected with battery of emf E with internal resistance r is given by

$$\text{Current,} \quad i = \frac{E}{R + r}$$

Case I $\quad 2 = \frac{E}{2 + r}$ ...(i)

Case II $\quad 0.5 = \frac{E}{9 + r}$ ...(ii)

From Eqs. (i) and (ii), we have,

$$\frac{2}{0.5} = \frac{9 + r}{2 + r}$$

$$4 = \frac{9 + r}{2 + r}$$

$$\Rightarrow \quad 3r = 1$$

$$\Rightarrow \quad r = \frac{1}{3}\ \Omega$$

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72 Consider the following two statements:

I. Kirchhoff's junction law follows from the conservation of charge.

II. Kirchhoff's loop law follows from the conservation of energy.

Which of the following is correct?

[CBSE AIPMT 2010]

(a) Both I and II are wrong

(b) I is correct and II is wrong

(c) I is wrong and II is correct

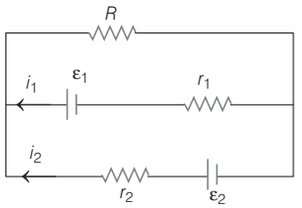
(d) Both I and II are correct

Ans. *(d)*

Kirchhoff's junction law follows from the conservation of charge.

Kirchhoff's loop law follows from the conservation of energy.

73 See the electrical circuit shown in this figure. Which of the following equations is a correct equation for it ? **[CBSE AIPMT 2009]**



(a) $\varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$

(b) $\varepsilon_2 - i_2 r_2 - \varepsilon_1 - i_1 r_1 = 0$

(c) $-\varepsilon_2 - (i_1 + i_2)R + i_2 r_2 = 0$

(d) $\varepsilon_1 - (i_1 + i_2)R + i_1 r_1 = 0$

Ans. *(a)*

The algebraic sum of the changes in potential in complete transversal of a mesh (closed loop) is zero. i.e. $\Sigma V = 0$

So, $\varepsilon_1 - (i_1 + i_2)R - i_1 r_1 = 0$

74 A student measures the terminal potential difference (V) of a cell (of emf ε and internal resistance r) as a function of the current (I) flowing through it. The slope and intercept of the graph between V and I, respectively, equal to **[CBSE AIPMT 2009]**

(a) ε and $-r$ (b) $-r$ and ε

(c) r and $-\varepsilon$ (d) $-\varepsilon$ and r

Ans. *(b)*

According to Ohm's law

$\frac{dV}{dI} = -r$ and $V = \varepsilon$ if $I = 0$

[As $V + Ir = \varepsilon$]

So, slope of the graph $= -r$ and intercept $= \varepsilon$

75 Two cells, having the same emf are connected in series through an external resistance R. Cells have internal resistances r_1 and r_2 ($r_1 > r_2$) respectively. When the circuit is closed, the potential difference across the first cell is zero. The value of R is **[CBSE AIPMT 2006]**

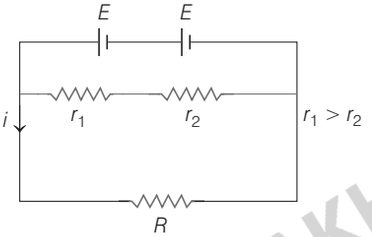
(a) $r_1 - r_2$ (b) $\frac{r_1 + r_2}{2}$

(c) $\frac{r_1 - r_2}{2}$ (d) $r_1 + r_2$

Ans. *(a)*

Net resistance of the circuit $= r_1 + r_2 + R$

Net emf in series $= E + E = 2E$



Therefore, from Ohm's law, current in the circuit

$$i = \frac{\text{Net emf}}{\text{Net resistance}}$$

$$\Rightarrow \quad i = \frac{2E}{r_1 + r_2 + R} \qquad \ldots(i)$$

It is given that, as circuit is closed, potential difference across the first cell is zero.

i.e., $V = E - ir_1 = 0$

$$\Rightarrow \quad i = \frac{E}{r_1} \qquad \ldots(ii)$$

Equating Eqs. (i) and (ii), we get

$$\frac{E}{r_1} = \frac{2E}{r_1 + r_2 + R} \Rightarrow 2r_1 = r_1 + r_2 + R$$

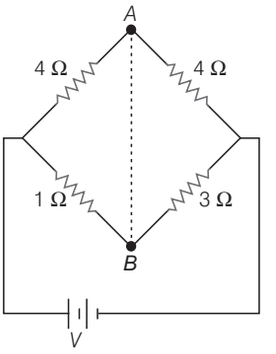
$\therefore$ $R =$ external resistance

$\Rightarrow$ $R = r_1 - r_2$

Note

The question is wrong as the statement is when the circuit is closed, the potential difference across the first cell is zero which implies that in a series circuit, one part cannot conduct current which is wrong, Kirchhoff 's law is violated. The question must have been modified.

76 In the circuit shown, if a conducting wire is connected between points A and B, the current in this wire will **[CBSE AIPMT 2006]**



(a) flow from A to B

(b) flow in the direction which will be decided by the value of V

(c) be zero

(d) flow from B to A

Ans. *(d)*

Resistances 4 Ω and 4 Ω are connected in series, so their effective resistance is

$R' = 4 + 4 = 8\,\Omega$

Similarly, 1 Ω and 3 Ω are in series

So, $R'' = 1 + 3 = 4\,\Omega$

Now R' and R'' will be in parallel, hence effective resistance

$$R = \frac{R' \times R''}{R' + R''}$$

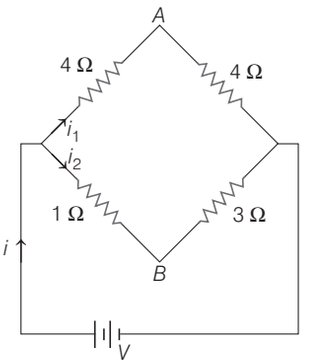
$$= \frac{8 \times 4}{8 + 4} = \frac{32}{12} = \frac{8}{3}\,\Omega$$

Current through the circuit, from Ohm's law

$$i = \frac{V}{R} = \frac{3V}{8}\,\text{A}$$

Let currents i_1 and i_2 flow in the branches as shown. As voltage remains same in parallel combination

i.e. $V_1 = V_2$



$\therefore$ $8i_1 = 4i_2$

$\Rightarrow$ $i_2 = 2i_1$ ...(i)

Also, $i = i_1 + i_2$

$\Rightarrow$ $\frac{3V}{8} = i_1 + 2i_1$

$\Rightarrow$ $i_1 = \frac{V}{8}\,\text{A}$ and $i_2 = \frac{V}{4}\,\text{A}$

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Potential drop at A,

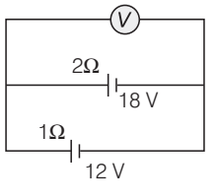
$$V_A = 4 \times i_1 = \frac{4V}{8} = \frac{V}{2}$$

Potential drop at B,

$$V_B = 1 \times i_2 = 1 \times \frac{V}{4} = \frac{V}{4}$$

Since, drop of potential is greater in $4\,\Omega$ resistance so, it will be at lower potential than B. Hence, on connecting wire between points A and B the current will flow from B to A.

77 Two batteries, one of emf 18V and internal resistance $2\,\Omega$ and the other of emf 12 V and internal resistance $1\,\Omega$, are connected as shown. The voltmeter V will record a reading of **[CBSE AIPMT 2005]**

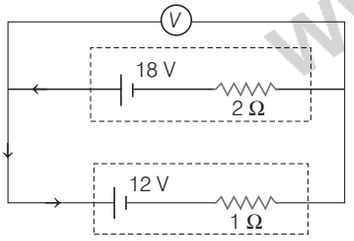


(a) 15 V (b) 30 V (c) 14 V (d) 18 V

Ans. *(c)*

It is clear that the two cells oppose each other hence, the effective emf in closed circuit is $18 - 12 = 6$ V and net resistance is $1 + 2 = 3\,\Omega$ (because in the closed circuit the internal resistances of two cells are in series).

The current in circuit will be in direction of arrow shown in figure.



$$I = \frac{\text{Effective emf}}{\text{Total resistance}} = \frac{6}{3} = 2\text{ A}$$

The potential difference across V will be same as the terminal voltage of either cell.

Since, current is drawn from the cell of 18 V, hence,

$$V_1 = E_1 - ir_1 = 18 - (2 \times 2) = 18 - 4 = 14\text{ V}$$

Similarly, current enters in the cell of 12 V, hence,

$$V_2 = E_2 + ir_2 = 12 + 2 \times 1 = 12 + 2 = 14\text{ V}$$

Hence, $V = 14$ V

78 A 6 V battery is connected to the terminals of a 3m long wire of uniform thickness and resistance of $100\,\Omega$. The difference of potential between two points on the wire separated by a distance of 50 cm will be **[CBSE AIPMT 2004]**

(a) 2 V (b) 3 V
(c) 1 V (d) 1.5 V

Ans. *(c)*

Total current drawn from the battery

$$i = \frac{E}{R + r} = \frac{6}{100 + 0} = 0.06\text{ A}$$

Resistance of 50 cm wire is

$$R' = \frac{\rho l'}{A} = \left(\frac{\rho}{A}\right) l' = \left(\frac{R}{l}\right) l' \quad \left(\because R = \frac{\rho l}{A}\right)$$

$$= \frac{100}{300} \times 50$$

So, $$R' = \frac{50}{3}\,\Omega$$

Hence, the potential difference between two points on the wire separated by a distance l' is given by Ohm's law

i.e. $$V = iR'$$

$$= 0.06 \times \frac{50}{3} = 1\text{ V}$$

79 A battery is charged at a potential of 15 V for 8 h when the current flowing is 10 A. The battery on discharge supplies a current of 5 A for 15 h. The mean terminal voltage during discharge is 14 V. The watt-hour efficiency of the battery is **[CBSE AIPMT 2004]**

(a) 82.5% (b) 80%
(c) 90% (d) 87.5%

Ans. *(d)*

Input energy when the battery is charged

$$E_{in} = Vit$$
$$= 15 \times 10 \times 8$$
$$= 1200\text{ Wh}$$

Energy released when the battery is discharged

$$E_{out} = 14 \times 5 \times 15$$
$$= 1050\text{ Wh}$$

Hence, watt hour efficiency of battery is given by

$$= \frac{\text{Energy output}}{\text{Energy input}} = \frac{1050}{1200}$$
$$= 0.875 = 87.5\%$$

80 For a cell, the terminal potential difference is 2.2V when circuit is open and reduces to 1.8 V when cell is connected to a resistance $R = 5\,\Omega$, the internal resistance (r) of cell is **[CBSE AIPMT 2002]**

(a) $\frac{10}{9}\,\Omega$ (b) $\frac{9}{10}\,\Omega$
(c) $\frac{11}{9}\,\Omega$ (d) $\frac{5}{9}\,\Omega$

Ans. *(a)*

In an open circuit, emf of cell

$$E = 2.2\text{ V}$$

In a closed circuit, terminal potential difference

$$V = 1.8\text{ V}$$

External resistance, $R = 5\,\Omega$

Thus, internal resistance of cell is

$$r = \left(\frac{E}{V} - 1\right) R = \left(\frac{2.2}{1.8} - 1\right) 5$$
$$= \left(\frac{11}{9} - 1\right) 5 = \frac{2}{9} \times 5 = \frac{10}{9}\,\Omega$$

81 A cell has an emf 1.5 V. When connected across an external resistance of $2\,\Omega$, the terminal potential difference falls to 1.0 V. The internal resistance of the cell is **[CBSE AIPMT 2000]**

(a) $2\,\Omega$ (b) $1.5\,\Omega$
(c) $1.0\,\Omega$ (d) $0.5\,\Omega$

Ans. *(c)*

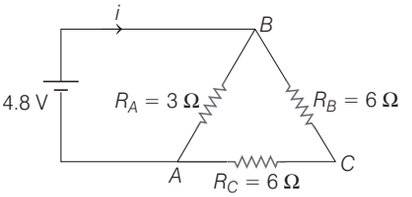
Internal resistance of the cell is given by

$$r = \left(\frac{E - V}{V}\right) R$$

Given, $E = 1.5$ V, $V = 1.0$ V, $R = 2\,\Omega$

$$\therefore \quad r = \left(\frac{1.5 - 1.0}{1.0}\right) \times 2 = \frac{0.5}{1.0} \times 2 = 1\,\Omega$$

82 The current (i) in the given circuit is **[CBSE AIPMT 1999]**



(a) 1.6 A (b) 2 A
(c) 0.32 A (d) 3.2 A

Ans. *(b)*

In the given circuit, resistances R_B and R_C are in series order, so their effective resistance,

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$$R' = R_B + R_C$$
$$= 6 + 6 = 12\ \Omega$$

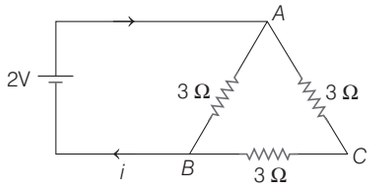
Now, R_A and R' are in parallel order, hence net resistance of the circuit

$$R = \frac{R' \times R_A}{R' + R_A} = \frac{12 \times 3}{12 + 3} = \frac{36}{15}\ \Omega$$

The current flowing in the circuit,

$$i = \frac{V}{R} = 4.8 \times \frac{15}{36} = 2\ \text{A}$$

83 The current in the following circuit is **[CBSE AIPMT 1997]**



(a) 1 A (b) $\frac{2}{3}$ A

(c) $\frac{2}{9}$ A (d) $\frac{1}{8}$ A

Ans. *(a)*

From the given figure, the resistances in the arms *AC* and *BC* are in series.

$$\therefore \quad R' = R_{AC} + R_{BC}$$
$$= 3\ \Omega + 3\ \Omega = 6\ \Omega$$

Now, R' is in parallel with the resistance in arm *AB*,

So, $$R = \frac{R' \times R_{AB}}{R' + R_{AB}}$$

$$= \frac{6\ \Omega \times 3\ \Omega}{6\ \Omega + 3\ \Omega} = 2\ \Omega$$

Therefore, the Ohm's law can be stated as

$$V = iR \quad \text{or} \quad \text{current}, i = \frac{V}{R}$$

Substituting the values, we get

$$i = \frac{2}{2} = 1\text{A} \qquad (\because V = 2\ \text{V})$$

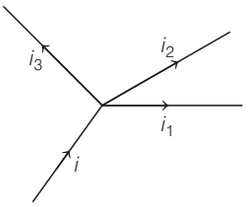
84 Kirchhoff's first law, i.e. $\Sigma i = 0$ at a junction, deals with the conservation of **[CBSE AIPMT 1997]**

(a) angular momentum
(b) linear momentum
(c) energy
(d) charge

Ans. *(d)*

Kirchhoff's law states that the algebraic sum of currents meeting at a point (say at a junction) is equals to zero i.e.,

$$\Sigma i = 0$$



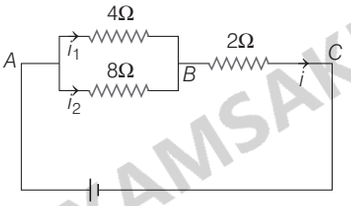
or $$i = i_1 + i_2 + i_3$$

$$\frac{dQ}{dt} = \frac{dQ_1}{dt} + \frac{dQ_2}{dt} + \frac{dQ_3}{dt}$$

or, $$dQ = dQ_1 + dQ_2 + dQ_3$$

So, we can say that when a steady current flows through circuit, then neither accumulation of charges takes place at the junction in the circuit nor any charge is removed from there. That's why Kirchhoff's first law deals with the conservation of charge.

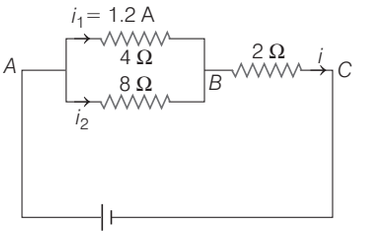
85 In the circuit of figure, the current in 4 Ω resistance is 1.2 A, what is the potential difference between *B* and *C*? **[CBSE AIPMT 1994]**



(a) 3.6 V (b) 6.3 V

(c) 1.8 V (d) 2.4 V

Ans. *(a)*



The potential difference across 4 Ω resistance is given by Ohm's law

$$= 4 \times i_1$$
$$= 4 \times 1.2 = 4.8\ \text{V} \qquad (\text{as } i_1 = 1.2\ \text{A})$$

As resistances 4 Ω and 8 Ω are in parallel, so potential difference across 8 Ω resistance will also be 4.8 V.

$\therefore$ Current through 8 Ω resistance

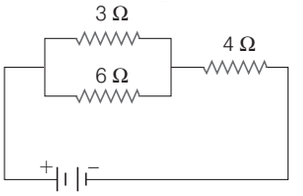
$$i_2 = \frac{V}{R} = \frac{4.8}{8} = 0.6\ \text{A}$$

$$\therefore \quad i = i_1 + i_2 = 1.2 + 0.6 = 1.8\ \text{A}$$

$\therefore$ Potential difference across 2 Ω resistance

$$V_{BC} = i \times 2$$
$$= 1.8 \times 2 = 3.6\ \text{V}$$

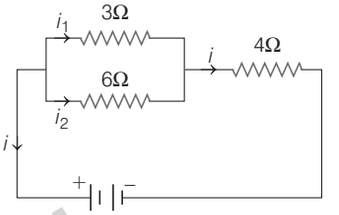
86 Current through 3 Ω resistor is 0.8 A, then potential drop through 4 Ω resistor is **[CBSE AIPMT 1993]**



(a) 9.6 V (b) 2.6 V

(c) 4.8 V (d) 1.2 V

Ans. *(c)*



Voltage across 3 Ω resistance is given by Ohm's law

i.e. $$V = IR = 3 \times i_1$$
$$= 3 \times 0.8 = 2.4\ \text{V} \quad (\text{as } i_1 = 0.8\ \text{A})$$

As 3 Ω and 6 Ω are in parallel, hence voltage across 6 Ω resistance will also be 2.4 V.

$\therefore$ Current through 6 Ω resistance

$$i_2 = \frac{V}{R} = \frac{2.4}{6} = 0.4\ \text{A}$$

$\therefore$ Total current in the circuit,

$$i = i_1 + i_2 = 0.8 + 0.4 = 1.2\ \text{A}$$

$\therefore$ Potential drop across 4 Ω resistance,

$$= i \times 4 = 1.2 \times 4 = 4.8\ \text{V}$$

87 Kirchhoff 's first law of electricity follows **[CBSE AIPMT 1992]**

(a) only law of conservation of energy
(b) only law of conservation of charge
(c) law of conservation of both energy and charge
(d) sometimes law of conservation of energy and some other times law of conservation of charge

Ans. *(b)*

Kirchhoff's first law supports law of conservation of charge. This is because a point in a circuit cannot act as a source or sink of charge.

88 A battery of emf 10 V and internal resistance **0.5 Ω** is connected across a variable resistance *R*. The value of *R* for which the power

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delivered in it is maximum, is given by **[CBSE AIPMT 1992]**

(a) 0.5 Ω (b) 1.0 Ω
(c) 2.0 Ω (d) 0.25 Ω

Ans. *(a)*

According to maximum power transfer theorem, the power output across load due to a cell or battery is maximum, if the load resistance is equal to the internal resistance of cell or battery. Hence, value of R will be 0.5 Ω.

89 Two identical batteries each of emf 2 V and internal resistance 1 Ω are available to produce heat in an external resistance by passing a current through it. The maximum power that can be developed across R using these batteries is **[CBSE AIPMT 1990]**

(a) 3.2 W (b) 2 W
(c) 1.28 W (d) $\frac{8}{9}$ W

Ans. *(b)*

To receive maximum current, the two batteries should be connected in series.

Given, $R = 1\Omega + 1\Omega = 2\,\Omega$.

Hence, power developed across the resistance R with the batteries in series is

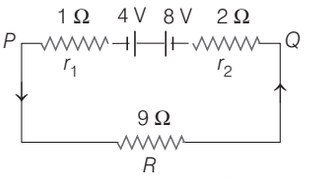
$$P = i^2R = \left(\frac{2E}{R+2r}\right)^2 R \qquad \left[I = \frac{E}{R_{eq}}\right]$$

$$= \left(\frac{2\times 2}{2+2}\right)\times 2 = 2\text{ W} \qquad [\because r = 1\Omega\,]$$

Note

In case of batteries connected in series, equivalent emf is given by $E_{eq} = E_1 + E_2$

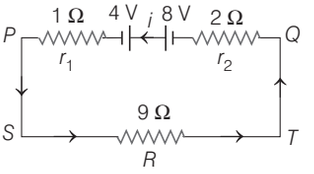
90 Two batteries of emf 4 V and 8 V with internal resistance 1 Ω and 2 Ω are connected in a circuit with a resistance of 9 Ω as shown in figure. The current and potential difference between the points P and Q are **[CBSE AIPMT 1988]**



(a) $\frac{1}{3}$ A and 3 V (b) $\frac{1}{6}$ A and 4 V
(c) $\frac{1}{9}$ A and 9 V (d) $\frac{1}{12}$ A and 12 V

Ans. *(a)*

Applying Kirchhoff's voltage law in the given loop and going in direction of current $PSTQ$ total voltage is equal to zero



So, $-2i + 8 - 4 - 1\times i - 9i = 0$

$\therefore \quad i = \frac{1}{3}$ A

Potential difference across $PQ = \frac{1}{3}\times 9$

$= 3$ V

TOPIC 4
Measuring Instruments

91 In a potentiometer circuit, a cell of emf 1.5 V gives balance point at 36 cm length of wire. If another cell of emf 2.5 V replaces the first cell, then at what length of the wire, the balance point occurs? **[NEET 2021]**

(a) 60 cm (b) 21.6 cm
(c) 64 cm (d) 62 cm

Ans. *(a)*

Given, length of balancing point, $L_1 = 36$ cm

$E_1 = 1.5$V

$E_2 = 2.5$V

We know that,

Potential gradient $= \frac{E}{L}$

$\because \quad \frac{E_1}{L_1} = \frac{E_2}{L_2}$

where, L_2 is the length of the balancing point for cell of emf E_2.

Substituting the values in the above equation, we get

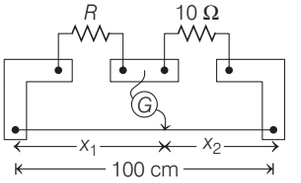
$$\frac{1.5}{36} = \frac{2.5}{L_2} \Rightarrow L_2 = 60\text{ cm}$$

92 A resistance wire connected in the left gap of a metre bridge balances a 10 Ω resistance in the right gap at a point which divides the bridge wire in the ratio 3 : 2. If the length of the resistance wire is 1.5 m, then the length of 1 Ω of the resistance wire is **[NEET (Sep.) 2020]**

(a) 1.0×10^{-1} m (b) 1.5×10^{-1} m
(c) 1.5×10^{-2} m (d) 1.0×10^{-2} m

Ans. *(a)*

According to the question, the metre bridge is shown below,



Given, $\frac{x_1}{x_2} = \frac{3}{2}$

At balance condition in metre bridge,

$$\frac{R}{10} = \frac{x_1}{x_2}$$

$$\Rightarrow \quad R = \frac{x_1}{x_2}\times 10 = \frac{3}{2}\times 10 = 15\,\Omega$$

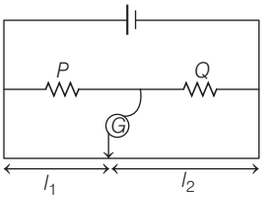
Now, length of given wire whose resistance 15 Ω is 1.5 m.

Therefore, length of 1Ω resistance wire is

$$= \frac{1.5}{15} = \frac{1}{10} = 0.1 = 1\times10^{-1}\text{ m}$$

Hence, correct option is (a).

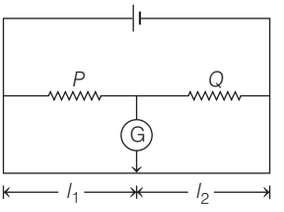
93 The meter bridge shown in the balance position with $\frac{P}{Q} = \frac{l_1}{l_2}$. If we now interchange the positions of galvanometer and cell, will the bridge work? If yes, that will be balanced condition? **[NEET (Odisha) 2019]**



(a) yes, $\frac{P}{Q} = \frac{l_2 - l_1}{l_2 + l_1}$ (b) no, no null point
(c) yes, $\frac{P}{Q} = \frac{l_2}{l_1}$ (d) yes, $\frac{P}{Q} = \frac{l_1}{l_2}$

Ans. *(d)*

For balanced position in a meterbridge



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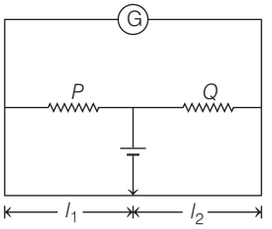
$$\frac{P}{Q}=\frac{l_1}{l_2}$$

Now, if position of G and cell is interchanged,



The balance condition still remains the same if the jockey points as the same point as given in the initial condition, for which there is no deflection in the galvanometer or no current will be drawn from the cell. Thus, the bridge will work as usual and balance condition is same, $P/Q=l_1/l_2$

94 A potentiometer is an accurate and versatile device to make electrical measurement of EMF because the method involves **[NEET 2017]**

(a) cells
(b) potential gradients
(c) a condition of no current flow through the galvanometer
(d) a combination of cells, galvanometer and resistances

Ans. *(c)*

When a cell is balanced against potential drop across a certain length of potentiometer wire, no current flows through the cell

$\therefore$ emf of cell = potential drop across balance length of potentiometer wire.

So, potentiometer is a more accurate device for measuring emf of a cell or no current flows through the cell during measurement of emf.

95 A potentiometer wire is 100 cm long and a constant potential difference is maintained across it. Two cells are connected in series first to support one another and then in opposite direction. The balance points are obtained at 50 cm and 10 cm from the positive end of the wire in the two cases. The ratio of emf is **[NEET 2016]**

(a) 5 : 4 (b) 3 : 4 (c) 3 : 2 (d) 5 : 1

Ans. *(c)*

According to question, emf of the cell is directly proportional to the balancing length i.e.

$$E\propto l \qquad ...(i)$$

Now, in the first case, cells are connected in series to support one another i.e.

Net emf $=E_1+E_2$

From Eq. (i), $E_1+E_2=50$ cm(given) ...(ii)

Again cells are connected in series in opposite direction i.e.

Net emf $=E_1-E_2$

From Eq. (i), $E_1-E_2=10$ ...(iii)

From Eqs. (ii) and (iii)

$$\frac{E_1+E_2}{E_1-E_2}=\frac{50}{10}\Rightarrow\frac{E_1}{E_2}=\frac{5+1}{5-1}=\frac{6}{4}=\frac{3}{2}$$

96 A potentiometer wire has length 4 m and resistance 8Ω. The resistance that must be connected in series with the wire and an accumulator of emf 2V, so as to get a potential gradient 1 mV per cm on the wire is **[CBSE AIPMT 2015]**

(a) 32 Ω (b) 40 Ω (c) 44 Ω (d) 48 Ω

Ans. *(a)*

Given, $l=4$ m,

$R=$ potentiometer wire resistance $=8\,\Omega$

Potential gradient $=\frac{dV}{dr}=1\,\text{mV/cm}$

So, for 400 cm, $\Delta V=400\times1\times10^{-3}=0.4$ V

Let a resistor R_S connected in series, so as

$$\Delta V=\frac{V}{R+R_S}\times R\Rightarrow 0.4=\frac{2}{8+R}\times8$$

$$\Rightarrow\quad 8+R=\frac{16}{0.4}=40\Rightarrow R=32\,\Omega$$

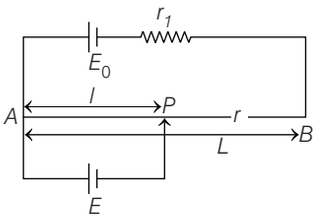
97 A potentiometer wire of length L and a resistance r are connected in series with a battery of e.m.f. E_0 and a resistance r_1. An unknown e.m.f. is balanced at a length l of the potentiometer wire. The e.m.f. E will be given by **[CBSE AIPMT 2015]**

(a) $\frac{LE_0r}{l\,r_1}$ (b) $\frac{E_0\,r}{(r+r_1)}\cdot\frac{l}{L}$

(c) $\frac{E_0\,l}{L}$ (d) $\frac{LE_0\,r}{(r+r_1)l}$

Ans. *(b)*

Consider a potentiometer wire of length L and a resistance r are connected in series with a battery of emf E_0 and a resistance r_1 as shown in figure. Current in wire $AB=\frac{E_0}{r_1+r}$



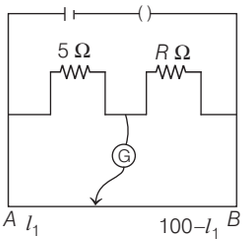
Potential gradient,

$$x=\frac{Ir}{L}=\left[\frac{E_0}{r_1+r}\right]\frac{r}{L}$$

emf produced across E will be given by

$$E=x\cdot l=\left[\frac{E_0r}{r_1+r}\right]\frac{l}{L}$$

98 The resistances in the two arms of the meter bridge are 5 Ω and R Ω, respectively. When the resistance R is shunted with an equal resistance, the new balance point is at 1.6 l_1. The resistance R, is **[CBSE AIPMT 2014]**



(a) 10 Ω (b) 15 Ω (c) 20 Ω (d) 25 Ω

Ans. *(b)*

For first case, balanced condition of meter bridge will be

$$\frac{5}{l_1}=\frac{R}{(100-l_1)} \qquad ...(i)$$

Now, by shunting resistance R by an equal resistance R, new resistance in that arm become $\frac{R}{2}$.

So, new balanced condition will be

$$\frac{5}{1.6l_1}=\frac{R/2}{(100-1.6l_1)} \qquad ...(ii)$$

From Eqs. (i) and (ii),

$$\frac{1.6}{1}=\frac{(100-1.6l_1)}{100-l_1}\times2$$

$$\Rightarrow 160-1.6l_1=200-3.2l_1$$

$$1.6l_1=40$$

$$l_1=\frac{40}{1.6}=25\text{ m}$$

$\Rightarrow$ From Eq. (i), $\frac{5}{25}=\frac{R}{75}\Rightarrow R=15\,\Omega$

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99 A potentiometer circuit has been set up for finding the internal resistance of a given cell. The main battery, used across the potentiometer wire, has an emf of 2.0 V and a negligible internal resistance. The potentiometer wire itself is 4 m long. When the resistance R, connected across the given cell, has values of (i) infinity, (ii) 9.5 Ω, the balancing lengths, on the potentiometer wire are found to be 3 m and 2.85 m, respectively.

The value of internal resistance of the cell is **[CBSE AIPMT 2014]**

(a) 0.25 Ω (b) 0.95 Ω
(c) 0.5 Ω (d) 0.75 Ω

Ans. *(c)*

Given, $e = 2\text{V}$ and $l = 4\text{m}$

Potential drop per unit length

$$\phi = \frac{e}{l} = \frac{2}{4} = 0.5\text{ V/m}$$

Case I

$$e' = \phi l_1 \quad \ldots(i)$$

(e' = emf of the given cell)

Case II

$$V = \phi l_2 \quad \ldots(ii)$$

From Eqs. (i) and (ii),

$$e'/V = l_1/l_2$$

$$\therefore \quad e' = I(r + R)$$

and $V = IR$ for the second case

$$\frac{I(r+R)}{IR} = \frac{l_1}{l_2}$$

So, $$r = R\left(\frac{l_1}{l_2} - 1\right) = 9.5\left(\frac{3}{2.85} - 1\right)$$

$$= 9.5(1.05 - 1)$$

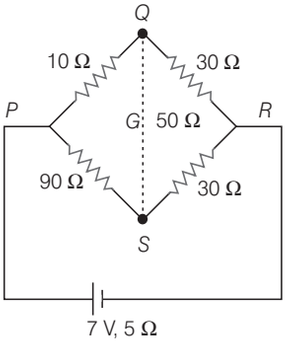
$$= 9.5 \times 0.05 = 0.475 \simeq 0.5\ \Omega$$

100 The resistances of the four arms P, Q, R and S in a Wheatstone bridge are 10 Ω, 30 Ω, 30 Ω and 90 Ω, respectively. The emf and internal resistance of the cell are 7 V and 5 Ω respectively. If the galvanometer resistance is 50 Ω, the current drawn from the cell will be **[NEET 2013]**

(a) 1.0 A
(b) 0.2 A
(c) 0.1 A
(d) 2.0 A

Ans. *(b)*

Effective resistance,



$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} \quad \ldots(i)$$

then, $$R_1 = 10 + 30$$

$$R_1 = 40$$

Now, $$R_2 = 90 + 30 = 120$$

$$R_2 = 120$$

By Eq. (i),

$$\frac{1}{R_{\text{eff}}} = \frac{1}{40} + \frac{1}{120}$$

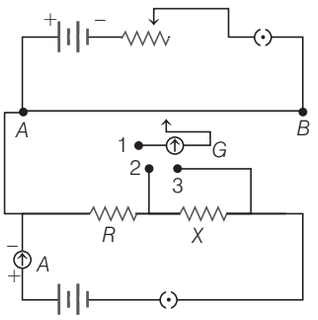
$$R_{\text{eff}} = \frac{40 \times 120}{120 + 40} = \frac{4800}{160} = 30\ \Omega$$

In the balancing condition,

$$\therefore \text{ Current, } I = \frac{7}{(30 + 5)} = \frac{7}{35} = 0.2\text{ A}$$

$$\left[\because I = \frac{E}{R + r}\right]$$

101 A potentiometer circuit is set up as shown. The potential gradient across the potentiometer wire, is k volt/cm and the ammeter, present in the circuit, reads 1.0 A when two way key is switched off. The balance points, when the key between the terminals (a) 1 and 2 (b) 1 and 3, is plugged in, are found to be at lengths l_1 cm and l_2 cm respectively. The magnitudes, of the resistors R and X in ohm, are then equal, respectively to **[CBSE AIPMT 2010]**



(a) $k(l_2 - l_1)$ and kl_2 (b) kl_1 and $k(l_2 - l_1)$
(c) $k(l_2 - l_1)$ and kl_1 (d) kl_1 and kl_2

Ans. *(c)*

The balancing length for R (when 1, 2 are connected) be l_1 and balancing length for $R + X$ (when 1, 3 is connected) is l_2.

Then, $iR = kl_1$ and $i(R + X) = kl_2$

Given, $i = 1\text{A}$

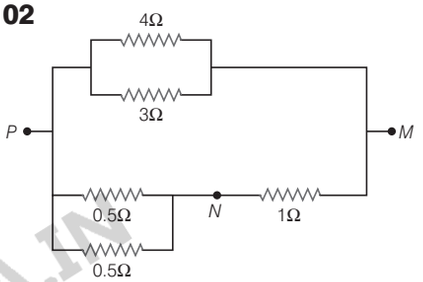
$\therefore$ $$R = kl_1 \quad \ldots(i)$$

$$R + X = kl_2 \quad \ldots(ii)$$

Also, subtracting Eq. (i) from Eq. (ii), we get

$$X = k(l_2 - l_1)$$

102



In the circuit shown, the current through the 4 Ω resistor is 1 A when the points P and M are connected to a DC voltage source. The potential difference between the points M and N is **[CBSE AIPMT 2008]**

(a) 1.5 V (b) 1.0 V (c) 0.5 V (d) 3.2 V

Ans. *(d)*

Potential across PM,

$$V_{PM} = 4 \times 1 = 4\text{ V}$$

Now, equivalent resistance across PN

$$\frac{1}{R_{\text{eq}}} = \frac{1}{0.5} + \frac{1}{0.5}$$

$$R_{\text{eq}} = \frac{0.5}{2} = 0.25\ \Omega$$

Effective resistance between P and M

$$R_{PM} = 0.25 + 1 = 1.25\ \Omega$$

For balancing condition,

$$\frac{V_{MN}}{V_{PM}} = \frac{R_{MN}}{R_{PM}}$$

$$V_{MN} = \frac{V_{PN} \times R_{MN}}{R_{PM}} = \frac{1}{1.25} \times 4 = 3.2\text{ V}$$

103. A cell can be balanced against 110 cm and 100 cm of potentiometer wire, respectively with and without being short circuited through a resistance of 10 Ω. Its internal resistance is **[CBSE AIPMT 2008]**

(a) 1.0 Ω (b) 0.5 Ω
(c) 2.0 Ω (d) zero

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Ans. *(a)*

In potentiometer experiment in which we find internal resistance of a cell. Let E be the emf of the cell and V be the terminal potential difference, then

$$\frac{E}{V}=\frac{l_1}{l_2}$$

where, l_1 and l_2 are lengths of potentiometer wire with and without being short circuited through a resistance.

Since, $\frac{E}{V}=\frac{R+r}{R}$

$[\because E=I(R+r) \text{ and } V=IR]$

$\therefore \quad \frac{R+r}{R}=\frac{l_1}{l_2} \quad \text{or} \quad 1+\frac{r}{R}=\frac{110}{100}$

or $\frac{r}{R}=\frac{10}{100}$ or $r=\frac{1}{10}\times 10=1\,\Omega$

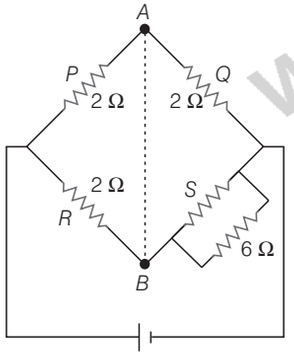
104 Three resistance P, Q, R each of $2\,\Omega$ and an unknown resistance S form the four arms of a Wheatstone bridge circuit. When a resistance of $6\,\Omega$ is connected in parallel to S the bridge gets balanced. What is the value of S? **[CBSE AIPMT 2007]**

(a) $2\,\Omega$ (b) $3\,\Omega$
(c) $6\,\Omega$ (d) $1\,\Omega$

Ans. *(b)*

Concept Balancing condition of Wheatstone bridge is used to calculate the value of unknown resistance.

The situation can be depicted as shown in figure.



As resistances S and $6\,\Omega$ are in parallel their effective resistance is

$$\frac{6S}{6+S}\,\Omega$$

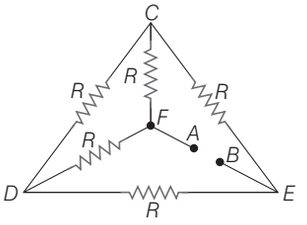
As the bridge is balanced, hence it is balanced Wheatstone bridge.

For balancing condition,

$$\frac{P}{Q}=\frac{R}{\left(\frac{6S}{6+S}\right)} \quad \text{or} \quad \frac{2}{2}=\frac{2(6+S)}{6S}$$

or $3S=6+S$ or $S=3\,\Omega$

105 Five equal resistances each of resistance R are connected as shown in the figure. A battery of $4V$ volts is connected between A and B. The current flowing in $AFCEB$ will be **[CBSE AIPMT 2004]**

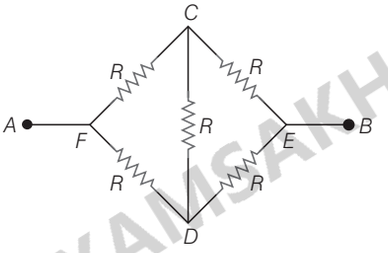


(a) $\frac{3V}{R}$ (b) $\frac{V}{R}$ (c) $\frac{V}{2R}$ (d) $\frac{2V}{R}$

Ans. *(c)*

The given circuit can be redrawn as shown.

From circuit, $\frac{FC}{CE}=\frac{FD}{DE}=1$



Thus, it is balanced Wheatstone bridge, so, resistance in arm CD is ineffective and so no current flows in this arm.

Net resistance of the circuit is

$$\frac{1}{R'}=\frac{1}{(R+R)}+\frac{1}{(R+R)}$$

$$=\frac{1}{2R}+\frac{1}{2R}=\frac{2}{2R}=\frac{1}{R}$$

$\therefore \quad R'=R$

So, net current drawn from the battery is

$$i'=\frac{V}{R'}=\frac{V}{R}$$

As from symmetry, upper circuit $AFCEB$ is half of the whole circuit and is equal to $AFDEB$.

So, in both the halves half of the total current will flow.

Hence, in $AFCEB$, the current flowing is

$$i=\frac{i'}{2}=\frac{V}{2R}$$

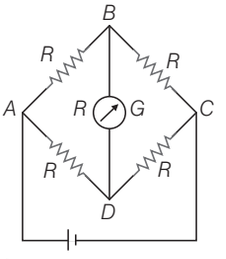
106 In a Wheatstone bridge, all the four arms have equal resistance R. If the resistance of the galvanometer arm is also R, the equivalent resistance of the combination as seen by the battery is **[CBSE AIPMT 2003]**

(a) R (b) $2R$
(c) $\frac{R}{4}$ (d) $\frac{R}{2}$

Ans. *(a)*

$$\frac{R_{AB}}{R_{BC}}=\frac{R_{AD}}{R_{DC}}$$

As bridge is in balanced condition, no current will flow through BD.



$R_1=R_{AB}+R_{BC}$
$=R+R$
$=2R$

$R_2=R_{AD}+R_{CD}$
$=R+R=2R$

R_1 and R_2 are in parallel combination.

Hence, equivalent resistance between A and C will be

$\therefore \quad R_{eq}=\frac{R_1R_2}{R_1+R_2}=\frac{4R^2}{4R}=R$

107 Resistivity of potentiometer wire is $10^{-7}\ \Omega$-m and its area of cross-section is $10^{-6}\ \text{m}^2$. When a current $i=0.1\text{A}$ flows through the wire, its potential gradient is **[CBSE AIPMT 2001]**

(a) 10^{-2} V/m (b) 10^{-4} V/m
(c) 0.1 V/m (d) 10 V/m

Ans. *(a)*

Potential gradient

= Potential fall per unit length $=\frac{V}{l}$

= current × resistance per unit length

$=i\times\frac{R}{l}$

but $R=\frac{\rho l}{A} \Rightarrow \frac{R}{l}=\frac{\rho}{A}$

where, symbols have their usual meanings.

$\therefore$ Potential gradient $=i\times\frac{\rho}{A}$

Here $\rho=10^{-7}\ \Omega$-m, $i=0.1$ A and $A=10^{-6}\ \text{m}^2$

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Hence, potential gradient $= 0.1 \times \frac{10^{-7}}{10^{-6}}$

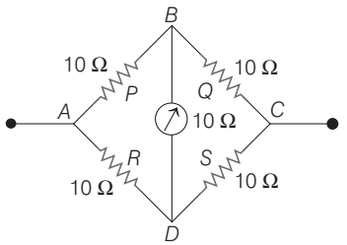
$= \frac{0.1}{10} = 0.01 = 10^{-2}$ V / m

108 In a Wheatstone bridge resistance of each of the four sides is 10 Ω. If the resistance of the galvanometer is also 10 Ω, then effective resistance of the bridge will be **[CBSE AIPMT 2001]**

(a) 10 Ω (b) 5 Ω
(c) 20 Ω (d) 40 Ω

Ans. *(a)*

The given circuit can be shown as,



From figure $\frac{P}{Q} = \frac{10}{10} = 1$

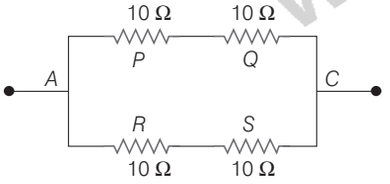
$\frac{R}{S} = \frac{10}{10} = 1$

$\therefore \quad \frac{P}{Q} = \frac{R}{S}$

Hence, Wheatstone bridge is balanced.

Therefore, the galvanometer will be ineffective.

The above Wheatstone bridge can be redrawn as



Resistances P and Q are in series, so

$R' = 10 + 10 = 20\ \Omega$

Resistances R and S are in series, so

$R'' = 10 + 10 = 20\ \Omega$

Now, R' and R'' are in parallel hence, net resistance of the circuit

$= \frac{R' \times R''}{R' + R''} = \frac{20 \times 20}{20 + 20} = 10\ \Omega$

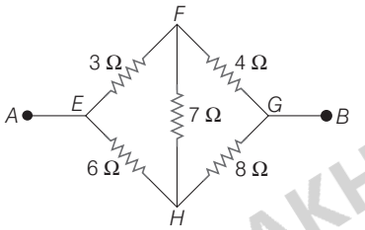
109 Potentiometer measures the potential difference more accurately than a voltmeter, because **[CBSE AIPMT 2000]**

(a) it has a wire of high resistance
(b) it has a wire of low resistance
(c) it does not draw current from external circuit
(d) it draws a heavy current from external circuit

Ans. *(c)*

When we measure the emf of a cell by the potentiometer then no current is drawn from the external circuit. Thus, in this condition the actual value of a cell is found. In this way potentiometer is equivalent to an ideal voltmeter of infinite resistance.

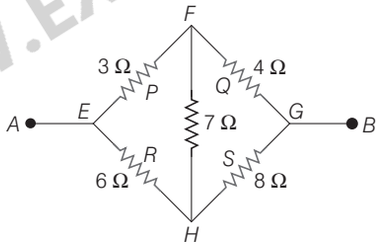
110 A bridge circuit is shown in figure. The equivalent resistance between A and B will be **[CBSE AIPMT 2000]**



(a) 21 Ω (b) 7 Ω (c) $\frac{252}{85}\ \Omega$ (d) $\frac{14}{3}\ \Omega$

Ans. *(d)*

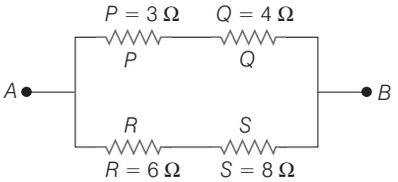
The bridge circuit can be shown as



The balanced condition of bridge circuit is given by

$\frac{P}{Q} = \frac{3}{4}, \frac{R}{S} = \frac{6}{8} = \frac{3}{4} \Rightarrow \frac{P}{Q} = \frac{R}{S}$

Thus, it is balanced Wheatstone bridge, so potential at F is equal to potential at H. Therefore, no current will flow through 7Ω resistance. So, circuit can be redrawn as



P and Q are in series, so their equivalent resistance = 3 + 4 = 7 Ω

R and S are also in series, so their equivalent resistance = 6 + 8 = 14 Ω

Now, 7 Ω and 14 Ω resistances are in parallel, so

$R_{AB} = \frac{7 \times 14}{7 + 14} = \frac{7 \times 14}{21} = \frac{14}{3}\ \Omega$

Note Normally, in Wheatstone bridge in middle arm galvanometer must be connected. In Wheatstone bridge, cell and galvanometer arms are interchangeable.

In both the cases, condition of balanced bridge is

$\frac{P}{Q} = \frac{R}{S}$

111 A potentiometer consists of a wire of length 4 m and resistance 10 Ω. It is connected to a cell of emf 2 V. The potential gradient of the wire is **[CBSE AIPMT 1999]**

(a) 0.5 V/m (b) 2 V/m
(c) 5 V/m (d) 10 V/m

Ans. *(a)*

Potential gradient $= \frac{\text{Potential applied}}{\text{Length of wire}}$

$\therefore \quad k = \frac{V}{l}$

Given, $V = 2$ V, $l = 4$ m

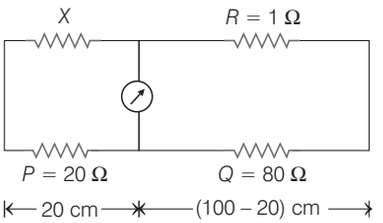
$\therefore \quad k = \frac{2}{4} = 0.5$ V/m

112 In meter bridge, the balancing length from left is found to be 20 cm when standard resistance of 1Ω is in right gap. The value of unknown resistance is **[CBSE AIPMT 1999]**

(a) 0.25 Ω (b) 0.4 Ω (c) 0.5 Ω (d) 4 Ω

Ans. *(a)*

Let unknown resistance be X.



Then condition of Wheatstone bridge gives, $\frac{X}{R} = \frac{20}{80}$

where, X = unknown resistance

R = known resistance

Hence, unknown resistance is

$X = \frac{20}{80} \times R = \frac{1}{4} \times 1 \quad (\because R = 1\ \Omega)$

$= 0.25\ \Omega$

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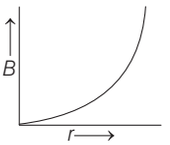
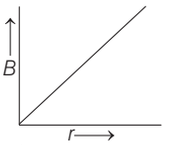
18

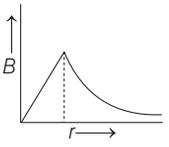
Moving Charges and Magnetism

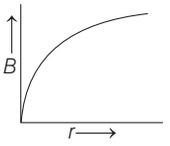
TOPIC 1
Biot Savart's Law and Ampere's Circuital Law

1 A thick current carrying cable of radius R carries current I uniformly distributed across its cross-section. The variation of magnetic field B due to the cable with the distance r from the axis of the cable is represented by **[NEET 2021]**

(a) 

(b) 

(c) 

(d) 

Ans. *(c)*

Magnetic field inside the conducting cylindrical cable,

$$B = \frac{\mu_0 I}{2\pi R^2} r$$

Here, R is the radius of the cylindrical cable,

r is the distance from the axis of the cylinder,

I is the current carrying in the cylindrical cable.

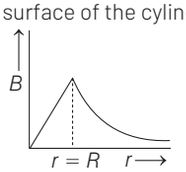
$\Rightarrow \quad B \propto r$

$\therefore$ The graph of magnetic field B with r is a straight line passing through origin.

For a point outside the cylinder,

$$B = \frac{\mu_0 I}{2\pi R} \Rightarrow B \propto \frac{1}{R}$$

The graph of magnetic field (B) with r is a rectangular hyperbola passing through the outer surface of the cylinder.



$\therefore$ The variation of the magnetic field B due to the cable with the distance r from the axis of the cylindrical cable is as shown in the figure.

2 A long solenoid of 50 cm length having 100 turns carries a current of 2.5 A. The magnetic field at the centre of solenoid is
(Take, $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}) **[NEET (Sep.) 2020]**

(a) 3.14×10^{-4} T (b) 6.28×10^{-5} T
(c) 3.14×10^{-5} T (d) 6.28×10^{-4} T

Ans. *(d)*

Given, $l = 50$ cm $= 0.5$m, $N = 100$ turns and $I = 2.5$A

$\therefore$ Magnetic field at the centre of solenoid is

$$= \mu_0 nI = \mu_0 \left(\frac{N}{l}\right) \cdot I$$

$$= 4\pi \times 10^{-7} \times \frac{100}{0.5} \times 2.5$$

$$= 6.28 \times 10^{-4} \text{ T}$$

Hence, correct option is (d).

3 Two toroids 1 and 2 have total number of turns 200 and 100 respectively with average radii 40 cm and 20 cm respectively. If they carry same current i, the ratio of the magnetic fields along the two loops is **[NEET (Odisha) 2019]**

(a) 1 : 1 (b) 4 : 1
(c) 2 : 1 (d) 1 : 2

Ans. *(a)*

The magnetic field within the turns of toroid is

$$B = \frac{\mu_0 NI}{2\pi r}$$

where, N = number of turns, I = current in loops and

r = radius of each turn

Here, $N_1 = 200$, $N_2 = 100$, $r_1 = 40$ cm, $r_2 = 20$ cm

and current I is same, then

$$\frac{B_1}{B_2} = \frac{\mu_0 N_1 I}{2\pi r_1} \times \frac{2\pi r_2}{\mu_0 N_2 I}$$

Substituting the given values in the above relation, we get

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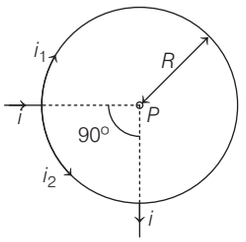
$$\frac{B_1}{B_2}=\left(\frac{N_1}{N_2}\right)\left(\frac{r_2}{r_1}\right)$$
$$=\left(\frac{200}{100}\right)\left(\frac{20}{40}\right)=2\times\frac{1}{2}=1$$
$$\therefore \quad B_1 : B_2 = 1:1$$

4 A straight conductor carrying current i splits into two parts as shown in the figure. The radius of the circular loop is R. The total magnetic field at the centre P at the loop is **[NEET (Odisha) 2019]**

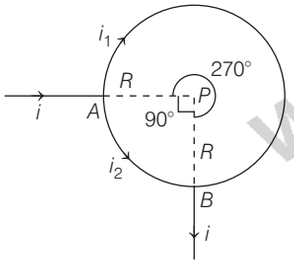


(a) Zero
(b) $3\mu_0 i / 32$ R, outward
(c) $3\mu_0 i /32$R, inward
(d) $\frac{\mu_0 i}{2R}$, inward

Ans. *(a)*

The magnetic field at the centre of an arc subtended at an angle θ is given by

$$B=\frac{\mu_0 i}{2R}\times\frac{\theta}{2\pi}$$



Then, the magnetic field due to larger arc AB is

$$B_1=\frac{\mu_0 i_1}{2R}\times\frac{270}{2\pi} \qquad ...(i)$$

which acts in inward direction according to right hand thumb rule. And magnetic field due to smaller arc AB is

$$B_2=\frac{\mu_0 i_2}{2R}\times\frac{90}{2\pi} \qquad ...(ii)$$

which acts in outward direction.

The resultant magnetic field

$$B_R = B_1 + B_2$$
$$=-\frac{\mu_0 i_1\times 270}{4\pi R}+\frac{\mu_0 i_2\times 90}{4\pi R}\text{ [From Eq. (i) and (ii)]} \qquad ...(iii)$$

which acts in inward direction as $B_1 > B_2$.

Two arcs can also be seen as the two resistances in parallel combination.

So, the potential across them will be same i.e.

$$V_1 = V_2$$
$$i_1 R_1 = i_2 R_2 \qquad ...(iv)$$

where, R_1 and R_2 = Resistance of respective segments

The wire is uniform so

$$\frac{R_1}{R_2}=\frac{L_1}{L_2}=\frac{R\times 270}{R\times 90}$$

[$\because$ length of arc = radius × angle]

From Eq. (iv), we get

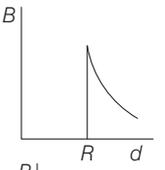
$$\Rightarrow \quad \frac{i_1}{i_2}=\frac{R_2}{R_1}=\frac{90}{270}=\frac{1}{3}$$

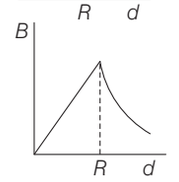
or $$3i_1 = i_2 \qquad ...(v)$$

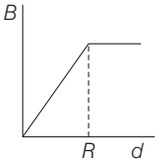
From Eq. (iii) and (v), we get

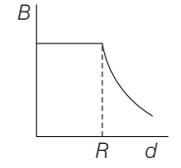
$$B_R=\frac{\mu_0}{4\pi R}(-270 i_1+90 i_2)$$
$$=\frac{\mu_0}{4\pi R}[-270 i_1+90(3 i_1)]$$
$$=\frac{\mu_0}{4\pi R}(-270 i_1+270 i_1)=0$$

5 A cylindrical conductor of radius R is carrying a constant current. The plot of the magnitude of the magnetic field B with the distance d from the centre of the conductor, is correctly represented by the figure **[NEET (National) 2019]**

(a)


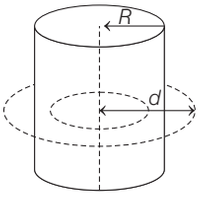
(b)


(c)


(d)


Ans. *(b)*

The cylinder can be considered to be made from concentric circles of radius R.



(i) The magnetic field at point outside cylinder, i.e. $d > R$.

From Ampere's circuital law,

$$\oint B\cdot dl=\mu_0 I$$
$$\Rightarrow \quad B\int dl=\mu_0 I$$
$$B(2\pi d)=\mu_0 I \;\Rightarrow\; B=\frac{\mu_0 I}{2\pi d}$$

where, μ_0 = permeability of free space.

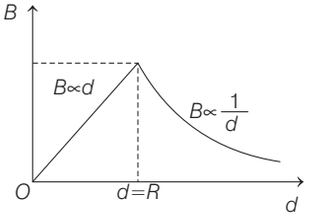
(ii) The magnitude field at surface, i.e. $d = R$

$$B=\frac{\mu_0 I}{2\pi R}$$

(iii) The magnetic field at inside point. The current for a point inside the cylinder is given by I' = current per unit cross-sectional area of cylinder × cross-section of loop

$$=\frac{I}{\pi R^2}\pi d^2=\frac{I d^2}{R^2}$$
$$\therefore \quad B=\frac{\mu_0 I'}{2\pi d}=\frac{\mu_0 I d^2}{2\pi R^2 d}=\frac{\mu_0 I}{2\pi R^2}d$$

So, the variation of magnetic field can be plotted as



6 A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields **B** and **B′** at radial distances $\frac{a}{2}$ and $2a$ respectively, from the axis of the wire is **[NEET 2016]**

(a) $\frac{1}{2}$ (b) 1
(c) 4 (d) $\frac{1}{4}$

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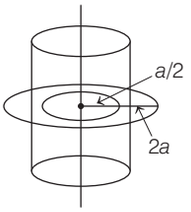
Ans. *(b)*

Consider two amperian loops of radius $\frac{a}{2}$ and $2a$ as shown in the diagram.

Applying Ampere's circuital law for these loops we get,



$$\oint \mathbf{B}.\mathbf{d}L = \mu_0 I_{\text{enclosed}}$$

For the smaller loop

$$\Rightarrow \quad B \times 2\pi\frac{a}{2} = \mu_0 \times \frac{I}{\pi a^2} \times \pi\left(\frac{a}{2}\right)^2$$

$$= \mu_0 I \times \frac{1}{4} = \frac{\mu_0 I}{4}$$

$$\Rightarrow B_I = \frac{\mu_0 I}{4\pi a}, \text{at distance } \frac{a}{2} \text{ from}$$

the axis of the wire.

Similarly, for bigger amperian loop.

$B' \times 2\pi(2a) = \mu_0 I$ [total current enclosed by Amperian loop is 2]

$$\Rightarrow \quad B' = \frac{\mu_0 I}{4\pi a},$$

at distance $2a$ from the axis of the wire.

So, ratio of, $\frac{B}{B'} = \frac{\mu_0 I}{4\pi a} \times \frac{4\pi a}{\mu_0 I} = 1$

7 A long wire carrying a steady current is bent into a circular loop of one turn. The magnetic field at the centre of the loop is B. It is then bent into a circular coil of n turns. The magnetic field at the centre of this coil of n turns will be **[NEET 2016]**

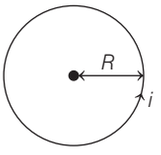
(a) nB (b) n^2B

(c) $2nB$ (d) $2n^2B$

Ans. *(b)*

Key Idea $B_{\text{centre}} = \frac{n \cdot \mu_0 i}{2R}$ (For a circular coil)

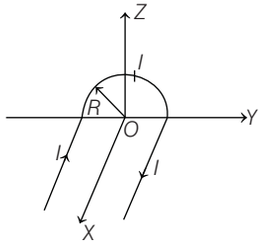
where, n : Number of turns in circular coil



$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0 i(2\pi)}{2(l)} = \frac{\mu_0 \pi i}{l}$$

$$= \frac{\mu_0 ni}{2\left(\frac{l}{2n\pi}\right)} = \frac{n^2 \mu_0 \pi i}{l} = n^2 B$$

8 A wire carrying current I has the shape as shown in adjoining figure. Linear parts of the wire are very long and parallel to X-axis while semicircular portion of radius R is lying in Y-Z plane. Magnetic field at point O is **[CBSE AIPMT 2015]**



(a) $\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} + 2\hat{\mathbf{k}})$

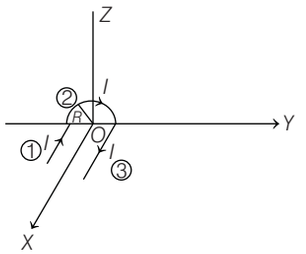
(b) $\mathbf{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} - 2\hat{\mathbf{k}})$

(c) $\mathbf{B} = -\frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} + 2\hat{\mathbf{k}})$

(d) $\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I}{R}(\pi\hat{\mathbf{i}} - 2\hat{\mathbf{k}})$

Ans. *(a)*

The magnetic field in the different regions is given by



$$\mathbf{B}_1 = \frac{\mu_0}{4\pi} \times \frac{I}{R}(-\hat{\mathbf{k}})$$

$$\mathbf{B}_3 = \frac{\mu_0 I}{4\pi R}(-\hat{\mathbf{k}})$$

$$\mathbf{B}_2 = \frac{\mu_0 I}{4\pi R}(-\hat{\mathbf{i}})$$

The net magnetic field at the centre O is

$$\mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 + \mathbf{B}_3$$

$$= \frac{\mu_0 I}{4\pi R}(-2\hat{\mathbf{k}}) + \frac{\mu_0 I}{4R}(-\hat{\mathbf{i}})$$

$$= -\frac{\mu_0 I}{4\pi R}(2\hat{\mathbf{k}} + \pi\hat{\mathbf{i}})$$

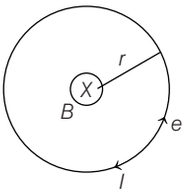
9 An electron moving in a circular orbit of radius r makes n rotations per second. The magnetic field produced at the centre has magnitude **[CBSE AIPMT 2015]**

(a) $\frac{\mu_0 ne}{2\pi r}$ (b) zero

(c) $\frac{\mu_0 n^2 e}{r}$ (d) $\frac{\mu_0 ne}{2r}$

Ans. *(d)*

As $I = \frac{q}{t}$. So, for an electron revolving in a circular orbit of radius r



$q = e$ and $t = T$

$$\Rightarrow I = \frac{e}{T} = \frac{e}{2\pi/\omega} = \frac{\omega e}{2\pi} = \frac{2\pi ne}{2\pi} = ne$$

The magnetic field produced at the centre is

$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0 ne}{2r}$$

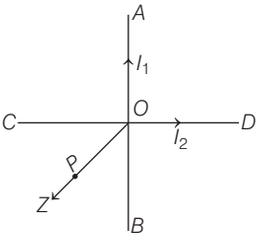
10 Two identical long conducting wires AOB and COD are placed at right angle to each other, such that one is above the other and O is their common point. The wires carry I_1 and I_2 currents, respectively. Point P is lying at distance d from O along a direction perpendicular to the plane containing the wires. The magnetic field at the point P will be **[CBSE AIPMT 2014]**

(a) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (b) $\frac{\mu_0}{2\pi d}(I_1 + I_2)$

(c) $\frac{\mu_0}{2\pi d}(I_1^2 - I_2^2)$ (d) $\frac{\mu_0}{2\pi d}(I_1^2 + I_2^2)^{1/2}$

Ans. *(d)*

As from question



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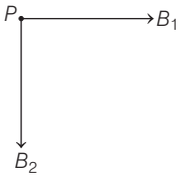
The point P is lying at a distance d along the Z-axis.



As magnetic field B_1 is given by $= \frac{\mu_0}{2\pi}\frac{I_1}{d}$

and magnetic field B_2 is given by $= \frac{\mu_0}{2\pi}\frac{I_2}{d}$

B_1 and B_2 are $\perp$ to each other

So, B_{net} is given by

$B_{net} = \sqrt{B_1^2 + B_2^2}$,

$B_{net} = \frac{\mu_0}{2\pi}\frac{1}{d}(I_1^2 + I_2^2)^{1/2}$

11 When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards West. When it is projected towards North with a speed v_0 it moves with an initial acceleration $3a_0$ towards West. The electric and magnetic fields in the room are **[NEET 2013]**

(a) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ up

(b) $\frac{ma_0}{e}$ West, $\frac{2ma_0}{ev_0}$ down

(c) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ up

(d) $\frac{ma_0}{e}$ East, $\frac{3ma_0}{ev_0}$ down

Ans. *(b)*

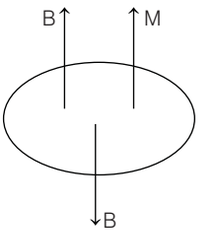
Initial acceleration is given by

$a_0 = \frac{eE}{m}$ $(F = eE)$

$\Rightarrow \quad E = \frac{a_0 m}{e}$ ...(i)

$\therefore \quad \frac{ev_0 B + eE}{m} = 3a_0$

or $ev_0 B + eE = 3a_0 m$



$\therefore \quad ev_0 B = 3ma_0 - eE$

$\Rightarrow \quad = 3ma_0 - ma_0$ [from Eq. (i)]

$\therefore B = \frac{2ma_0}{ev_0}$, in vertically downward direction

12 Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $2I$, respectively. The resultant magnetic field induction at the centre will be **[CBSE AIPMT 2012]**

(a) $\frac{\sqrt{5}\mu_0 I}{2R}$ (b) $\frac{3\mu_0 I}{2R}$

(c) $\frac{\mu_0 I}{2R}$ (d) $\frac{\mu_0 I}{R}$

Ans. *(a)*

The magnetic field (B) at the centre of circular current carrying coil of radius R and current I is $B = \frac{\mu_0 I}{2R}$

Similarly, if current is $2I$, then

Magnetic field $= \frac{\mu_0 2I}{2R} = 2B$

So, resultant magnetic field

$= \sqrt{B^2 + (2B)^2} = \sqrt{5B^2}$

$= \sqrt{5}B = \frac{\mu_0 I\sqrt{5}}{2R}$

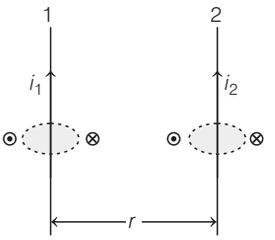
13 Two wires are held perpendicular to the plane of paper and are 5 m apart. They carry currents of 2.5 A and 5 A in same direction. Then, the magnetic field strength (**B**) at a point midway between the wires will be **[CBSE AIPMT 2008]**

(a) $\frac{\mu_0}{4\pi}$ T (b) $\frac{\mu_0}{2\pi}$ T

(c) $\frac{3\mu_0}{2\pi}$ T (d) $\frac{3\mu_0}{4\pi}$ T

Ans. *(b)*

According to Maxwell's right handed screw rule, the magnetic field at right hand of wire 1 is perpendicular to the current carrying wire in plane of paper going inwards shown by $\otimes$. Similarly, the magnetic field at left hand of wire 2 is perpendicular to current carrying wire in plane of paper opposite to first wire shown by $\odot$. Thus, the two fields are opposite to each other.



Therefore, net magnetic field

$B = B_1 - B_2 = \frac{\mu_0 i_1}{2\pi r_1} - \frac{\mu_0 i_2}{2\pi r_2}$

At mid-point, $r_1 = r_2 = \frac{r}{2} = \frac{5}{2} = 2.5\,\text{cm}$

Hence, $B = \frac{\mu_0}{2\pi}\left(\frac{i_1}{r/2} - \frac{i_2}{r/2}\right)$

$= \frac{\mu_0}{2\pi}\left(\frac{5}{2.5} - \frac{2.5}{2.5}\right)$

$= \frac{\mu_0}{2\pi}(2-1) = \frac{\mu_0}{2\pi}\,\text{T}$

14 Two circular coils 1 and 2 are made from the same wire but the radius of the 1st coil is twice that of the 2nd coil. What is the ratio of potential difference applied across them so that the magnetic field at their centres is the same ? **[CBSE AIPMT 2006]**

(a) 3 (b) 4 (c) 6 (d) 2

Ans. *(b)*

Magnetic field at the centre of a circular coil is

$B = \frac{\mu_0}{2\pi} \times \frac{i}{r}$

where, i is current flowing in the coil and r is radius of coil.

At the centre of coil-1,

$B_1 = \frac{\mu_0}{2\pi} \times \frac{i_1}{r_1}$ ...(i)

At the centre of coil-2

$B_2 = \frac{\mu_0}{2\pi} \times \frac{i_2}{r_2}$ ...(ii)

but $B_1 = B_2$

$\therefore \quad \frac{\mu_0}{2\pi}\frac{i_1}{r_1} = \frac{\mu_0}{2\pi}\frac{i_2}{r_2}$

or $\frac{i_1}{r_1} = \frac{i_2}{r_2}$

As given $r_1 = 2r_2$

$\therefore \quad \frac{i_1}{2r_2} = \frac{i_2}{r_2}$ or $i_1 = 2i_2$ ...(iii)

Now, ratio of potential differences

$\frac{V_2}{V_1} = \frac{i_2 \times R_2}{i_1 \times R_1} = \frac{i_2 \times R_2}{2i_2 \times 2R_2} = \frac{1}{4}$ $[R \propto r]$

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$\therefore \quad \frac{V_1}{V_2} = \frac{4}{1}$

Note If wires are made of same material, then resistance of coil is proportional to the radius of coil
i.e., $R \propto I$ so, $R \propto 2\pi r$

15 A long solenoid carrying a current produces a magnetic field B along its axis. If the current is doubled and the number of turns per cm is halved, the new value of the magnetic field is **[CBSE AIPMT 2003]**

(a) $2B$ (b) $4B$ (c) $\frac{B}{2}$ (d) B

Ans. *(d)*

For a solenoid magnetic field is given by $B = \mu_0 ni$
where, n = number of turns per unit length and i = current through the coil
or so for two different cases $B \propto ni$

$\therefore \quad \frac{B_1}{B_2} = \frac{n_1 i_1}{n_2 i_2}$

Here, $n_1 = n, \; n_2 = \frac{n}{2}$,

$i_1 = i, \; i_2 = 2i, \; B_1 = B$

Hence, $\frac{B}{B_2} = \frac{n}{n/2} \times \frac{i}{2i} = 1$ or $B_2 = B$

16 The magnetic field of a given length of wire carrying a current for a single turn circular coil at centre is B, then its value for two turns for the same wire when same current passing through it is **[CBSE AIPMT 2002]**

(a) $\frac{B}{4}$ (b) $\frac{B}{2}$ (c) $2B$ (d) $4B$

Ans. *(d)*

Magnetic field at the centre of circular coil carrying current i with N number of turns is given by

$$B = \frac{\mu_0 Ni}{2r}$$

Case I $N = 1, L = 2\pi r \Rightarrow r = \frac{L}{2\pi}$

$\therefore \quad B = \frac{\mu_0 \times 1 \times i}{2r} = \frac{\mu_0 i}{2r}$

Case II $N = 2, L = 2 \times 2\pi r'$

$\Rightarrow r' = \frac{L}{4\pi} = \frac{r}{2} \quad \therefore \quad B' = \frac{\mu_0 \times 2 \times i}{2r'}$

Putting the value of r'

$$B' = \frac{\mu_0 \times 2i}{2 \times (r/2)} = \frac{4\mu_0 i}{2r} = 4B$$

Note Magnetic field at the centre of circular coil is maximum and decreases as we move away from the centre (on the axis of coil).

17 Magnetic field due to 0.1A current flowing through a circular coil of radius 0.1m and 1000 turns at the centre of the coil is **[CBSE AIPMT 1999]**

(a) 0.2 T (b) 2×10^{-4} T
(c) 6.28×10^{-4} T (d) 9.8×10^{-4} T

Ans. *(c)*

At the centre of current carrying, circular coil, the magnetic field is,

$$B = \frac{\mu_0 Ni}{2r}$$

where, N = number of turns in the coil
i = current flowing
r = radius of the coil
Given, $N = 1000$, $i = 0.1$ A, $r = 0.1$ m
Substituting the values, we have

$$B = \frac{4\pi \times 10^{-7} \times 1000 \times 0.1}{2 \times 0.1}$$

$$= 2\pi \times 10^{-4} = 6.28 \times 10^{-4} \text{ T}$$

18 If a long hollow copper pipe carries a current, then magnetic field is produced
(a) inside the pipe only **[CBSE AIPMT 1999]**
(b) outside the pipe only
(c) both inside and outside the pipe
(d) no where

Ans. *(b)*

According to Ampere's circuital law,

$$\int B \cdot dl = \mu_0 i_{\text{enclosed}}$$

So, $B(2\pi r) = \mu_0 \times 0 \quad [i_{\text{enclosed}} = 0]$

$\therefore \quad B = 0$

So, inside a hollow metallic (copper) pipe there is no current inside the Ampere's surface so, the magnetic field is zero. But for external points, the whole current behaves as if it were concentrated at the axis only, so outside

$$B_0 = \frac{\mu_0 i}{2\pi r}$$

Thus, the magnetic field is produced outside the pipe only.

19 A coil of one turn is made of a wire of certain length and then from the same length a coil of two turns is made. If the same current is passed in both the cases, then the ratio of the magnetic induction at their centres will be **[CBSE AIPMT 1998]**

(a) 2 : 1 (b) 1 : 4
(c) 4 : 1 (d) 1 : 2

Ans. *(b)*

Magnetic induction at the centre of current carrying coil of N turns carrying current is given by

$$B = \frac{\mu_0 Ni}{2r} \quad \ldots(i)$$

Suppose the length of the wire be L.
Case I For coil of one turn, let radius be r_1.

$\therefore \quad L = 2\pi r_1 \times N$

or $r_1 = \frac{L}{2\pi \times N} = \frac{L}{2\pi} \quad (\because N = 1)$

Case II For coil of two turns, let radius be r_2.

$\therefore \quad L = 2\pi r_2 \times N$

or $r_2 = \frac{L}{2\pi \times N} = \frac{L}{2\pi \times 2} \quad (\because N = 2)$

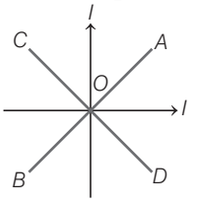
or $r_2 = \frac{r_1}{2}$

By comparing two different cases from Eq. (i),

$$\frac{B_1}{B_2} = \frac{N_1}{r_1} \times \frac{r_2}{N_2} \quad \text{or} \quad \frac{B_1}{B_2} = \frac{1 \times \frac{r_1}{2}}{r_1 \times 2}$$

$\therefore \quad \frac{B_1}{B_2} = \frac{1}{4}$

20 Two equal electric currents are flowing perpendicular to each other as shown in the figure. AB and CD are perpendicular to each other and symmetrically placed w.r.t the currents, where do we expect the resultant magnetic field to be zero ? **[CBSE AIPMT 1996]**



(a) On AB
(b) On CD
(c) On both AB and CD
(d) On both OD and BO

Ans. *(a)*

Applying right hand grip rule and considering AB, the direction of magnetic field due to one current is

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upwards and that due to other is downwards. Both the magnetic fields cancel out each other and the resultant magnetic field is zero.

Considering CD and applying right hand grip rule for the two currents, the direction of magnetic field is in the same direction in both the cases giving non-zero resultant.

21 The magnetic field **dB** due to a small element at a distance **r** and carrying current i is **[CBSE AIPMT 1996]**

(a) $\mathbf{dB} = \frac{\mu_0}{4\pi} i \left(\frac{\mathbf{dl} \times \mathbf{r}}{r}\right)$

(b) $\mathbf{dB} = \frac{\mu_0}{4\pi} i^2 \left(\frac{\mathbf{dl} \times \mathbf{r}}{r^2}\right)$

(c) $\mathbf{dB} = \frac{\mu_0}{4\pi} i^2 \left(\frac{\mathbf{dl} \times \mathbf{r}}{r}\right)$

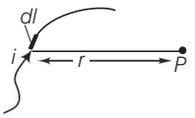
(d) $\mathbf{dB} = \frac{\mu_0}{4\pi} i \left(\frac{\mathbf{dl} \times \mathbf{r}}{r^3}\right)$

Ans. *(d)*

According to Biot-Savart law, the magnetic field induction **dB** (also called magnetic flux density) at a point P due to current element depends upon the factors as stated below.

(i) $dB \propto i$ (ii) $dB \propto dl$

(iii) $dB \propto \sin\theta$ (iv) $dB \propto \frac{1}{r^2}$



Combining these factors, we get magnitude of **dB**

i.e., $\mathbf{dB} = \frac{\mu_0}{4\pi} \cdot \frac{i\, dl \sin\theta}{r^2}$

In vector form,

$\mathbf{dB} = \frac{\mu_0}{4\pi} i \frac{(\mathbf{dl} \times \mathbf{r})}{r^3} \quad \left[\frac{\mu_0}{4\pi} = 10^{-7}\ \text{T-m/A}\right]$

22 At what distance from a long straight wire carrying a current of 12 A will the magnetic field be equal to 3×10^{-5} Wb/m^2 ? **[CBSE AIPMT 1995]**

(a) 8×10^{-2} m (b) 12×10^{-2} m

(c) 18×10^{-2} m (d) 24×10^{-2} m

Ans. *(a)*

Total magnetic field due to current carrying straight wire at any point P is given by

$$B = \frac{\mu_0 i}{4\pi r}(\sin\phi_1 + \sin\phi_2)$$

When the conductor is of infinite length and point P lies near the centre of conductor, then $\phi_1 = \phi_2 = 90°$

$$\therefore \quad B = \frac{\mu_0 i}{4\pi r}(\sin 90° + \sin 90°)$$

$$= \frac{\mu_0}{4\pi} \cdot \frac{2i}{r} \Rightarrow r = \frac{\mu_0 i}{2\pi B}$$

Here, current $(i) = 12$ A,

magnetic field $(B) = 3 \times 10^{-5}$ Wb / m^2

$\therefore$ Perpendicular distance from wire to the point, $r = \frac{4\pi \times 10^{-7} \times 12}{2 \times \pi \times (3 \times 10^{-5})}$

$$= 8 \times 10^{-2} \text{ m}$$

23 A straight wire of diameter 0.5 mm carrying a current of 1 A is replaced by another wire of 1 mm diameter carrying same current. The strength of magnetic field far away is **[CBSE AIPMT 1995]**

(a) twice the earlier value

(b) same as the earlier value

(c) one-half of the earlier value

(d) one-quarter of the earlier value

Ans. *(b)*

Magnetic field due to straight wire is given by

$$B = \frac{\mu_0}{4\pi} \frac{2i}{r}$$

From above expression magnetic field due to current carrying conductor doesn't depends on the diameter of wire, it only depends on distance of wire from the point and current in the wire so, magnetic field reamaining same for both wires.

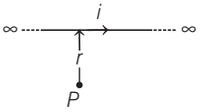
24 The magnetic field at a distance r from a long wire carrying current i is 0.4 T. The magnetic field at a distance $2r$ is **[CBSE AIPMT 1992]**

(a) 0.2 T (b) 0.8 T

(c) 0.1 T (d) 1.6 T

Ans. *(a)*

Magnetic field due to a long current carrying wire at distance r at point P is given by



$$B = \frac{\mu_0}{4\pi} \cdot \frac{2i}{r}$$

So, $B \propto \frac{1}{r}$

when r is doubled, the magnetic field becomes halved.

i.e., $B' = \frac{B}{2} \Rightarrow B' = \frac{0.4}{2} = 0.2$ T

25 The magnetic induction at a point P which is at the distance of 4 cm from a long current carrying wire is 10^{-3} T. The field of induction at a distance 12 cm from the current will be **[CBSE AIPMT 1990]**

(a) 3.33×10^{-4} T (b) 1.11×10^{-4} T

(c) 3×10^{-3} T (d) 9×10^{-3} T

Ans. *(a)*

Magnetic field due to a long straight conductor carrying current i at a distance r is given by

$$B = \frac{\mu_0}{4\pi} \frac{2i}{r}$$

Given, $r_1 = 4$ cm, $r_2 = 12$ cm.

As $B \propto \frac{1}{r}$

and distance becomes 3 times, field is reduced to its one-third value.

Hence, $B' = \frac{B}{3} = \frac{10^{-3}}{3} = 3.33 \times 10^{-4}$ T

26 Tesla is the unit of **[CBSE AIPMT 1988]**

(a) magnetic flux

(b) magnetic field

(c) magnetic induction

(d) magnetic moment

Ans. *(c)*

SI unit of magnetic induction is tesla (T).

Magnetic field induction at a point is said to be one tesla if a charge of one coulomb while moving at right angle to a magnetic field, with a velocity of 1 ms^{-1} experiences a force of 1 N, at that point.

$\therefore \quad 1\text{T} = 1\text{NA}^{-1}\text{ m}^{-1}$

TOPIC 2

Magnetic Force on Charged Particle in Magnetic Field

27 In the product

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

$$= q\mathbf{v} \times (B\hat{\mathbf{i}} + B\hat{\mathbf{j}} + B_0\hat{\mathbf{k}})$$

For $q = 1$ and $\mathbf{v} = 2\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 6\hat{\mathbf{k}}$ and

$\mathbf{F} = 4\hat{\mathbf{i}} - 20\hat{\mathbf{j}} + 12\hat{\mathbf{k}}$

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What will be the complete expression for **B**? **[NEET 2021]**

(a) $-8\hat{\mathbf{i}}-8\hat{\mathbf{j}}-6\hat{\mathbf{k}}$

(b) $-6\hat{\mathbf{i}}-6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$

(c) $8\hat{\mathbf{i}}+8\hat{\mathbf{j}}-6\hat{\mathbf{k}}$

(d) $6\hat{\mathbf{i}}+6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$

Ans. *(b)*

Given, velocity, $\mathbf{v}=2\hat{\mathbf{i}}+4\hat{\mathbf{j}}+6\hat{\mathbf{k}}$

Force, $\mathbf{F}=4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}$

As we know,

$$\mathbf{F}=q(\mathbf{v}\times\mathbf{B})$$

Here, $q=1$ (given)

Substituting the values in the above equation, we get

$$4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=(1)[(2\hat{\mathbf{i}}+4\hat{\mathbf{j}}+6\hat{\mathbf{k}})\times(B\hat{\mathbf{i}}+B\hat{\mathbf{j}}+B_0\hat{\mathbf{k}})]$$

$$4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=\begin{pmatrix}\hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}}\\ 2 & 4 & 6\\ B & B & B_0\end{pmatrix}$$

$$\Rightarrow 4\hat{\mathbf{i}}-20\hat{\mathbf{j}}+12\hat{\mathbf{k}}=\hat{\mathbf{i}}(4B_0-6B)-\hat{\mathbf{j}}(2B_0-6B)+\hat{\mathbf{k}}(2B-4B)$$

Comparing the LHS and RHS of the above equation, we get

$\hat{\mathbf{i}}$ terms:

$$4B_0-6B=4 \quad ...(i)$$

$\hat{\mathbf{j}}$ terms:

$$2B_0-6B=20 \quad ...(ii)$$

$\hat{\mathbf{k}}$ terms:

$$2B-4B=12$$

$$\Rightarrow B=-6$$

Substituting the value of B in the Eq. (ii), we get

$$2B_0-6(-6)=20 \Rightarrow B_0=-8$$

Thus, the magnetic field vector,

$$B=-6\hat{\mathbf{i}}-6\hat{\mathbf{j}}-8\hat{\mathbf{k}}$$

28 Ionised hydrogen atoms and α -particles with same momenta enters perpendicular to a constant magnetic field, B.The ratio of their radii of their paths $r_H : r_\alpha$ will be **[NEET (National) 2019]**

(a) 1 : 2 (b) 4 : 1

(c) 1 : 4 (d) 2 : 1

Ans. *(d)*

The centripetal force required for circular motion is provided by magnetic force

$$\Rightarrow \frac{mv_p^2}{r}=Bqv_p$$

$$\Rightarrow r=\frac{mv_p}{qB} \quad ...(i)$$

where, v_p = perpendicular velocity of particle and

q = charge on particle.

As, momentum, $p=mv_p$

$$\therefore r=\frac{p}{qB} \quad [\text{from Eq. (i)}]$$

According to the question, moment of both particle is same.

$$\Rightarrow r\propto\frac{1}{q}$$

For ionised hydrogen atom, $q_H=e$

and for α-particle, $q_\alpha=2e$

$$\Rightarrow \frac{r_H}{r_\alpha}=\frac{q_\alpha}{q_H}=\frac{2e}{e}=\frac{2}{1} \text{ or } 2:1$$

29 An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is **[NEET 2016]**

(a) 1 GHz (b) 100 MHz

(c) 62.8 MHz (d) 6.28 MHz

Ans. *(a)*

As we know that, radius of a charged particle in a magnetic field B is given by

$$r=\frac{mv}{qB} \quad ...(i)$$

where, r = charge on the particle

v = speed of the particle

$\therefore$ The time taken to complete the circle,

$$T=\frac{2\pi r}{v}\Rightarrow\frac{T}{2\pi}=\frac{m}{qB} \quad [\text{from Eq. (i)}]$$

$$\therefore \omega=\frac{2\pi}{T}=\frac{qB}{m}$$

$$\because q=e \text{ and } \frac{e}{m}=1.76\times10^{11} \text{ C/kg}$$

$$B=3.57\times10^{-2} \text{ T}$$

$$\Rightarrow \frac{2\pi}{T}=\frac{eB}{m} f=\frac{1}{2\pi}\frac{e}{m}B \quad \left(\because \frac{1}{T}=f\right)$$

$$=\frac{1}{2\pi}\times1.76\times10^{11}\times3.57\times10^{-2}$$

$$=1.0\times10^9 \text{ Hz}=1 \text{ GHz}$$

30 An alternating electric field of frequency ν, is applied across the dees (radius = R) of a cyclotron that is being used to accelerate protons (mass = m). The operating magnetic field (B) used in the cyclotron and the kinetic energy (K) of the proton beam, produced by it, are given by **[CBSE AIPMT 2012]**

(a) $B=\frac{m\nu}{e}$ and $K=2m\pi^2\nu^2R^2$

(b) $B=\frac{2\pi m\nu}{e}$ and $K=m^2\pi\nu R^2$

(c) $B=\frac{2\pi m\nu}{e}$ and $K=2m\pi^2\nu^2R^2$

(d) $B=\frac{m\nu}{e}$ and $K=m^2\pi\nu R^2$

Ans. *(c)*

Frequency, $\nu=\frac{eB}{2\pi m}$

KE $=\frac{1}{2}m\nu^2$ and radius $R=\frac{m\nu}{eB}$

Here, velocity, $v=\frac{\pi R}{T/2}=\frac{2\pi R}{T}=2\pi R\nu$

$\therefore$ Radius, $R=\frac{m(2\pi R\nu)}{eB}$

Magnetic field, $B=\frac{2\pi m\nu}{e}$

Kinetic energy, $K=\frac{1}{2}m(2\pi R\nu)^2$

$$=2m\pi^2\nu^2R^2$$

31 A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected in the region such that its velocity is pointed along the direction of fields, then the electron **[CBSE AIPMT 2011]**

(a) speed will decrease

(b) speed will increase

(c) ill turn towards left of direction of motion

(d) will turn towards right of direction of motion

Ans. *(a)*

Magnetic field (B) will not apply any force. Only electric field **E** will apply a force opposite to velocity of the electron hence, speed decreases.

32 A beam of cathode rays is subjected to crossed electric (E) and magnetic fields (B). The fields are adjusted such that the beam is not deflected. The specific charge of the cathode rays is given by **[CBSE AIPMT 2010]**

(a) $\frac{B^2}{2VE^2}$ (b) $\frac{2VB^2}{E^2}$

(c) $\frac{2VE^2}{B^2}$ (d) $\frac{E^2}{2VB^2}$

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Ans. *(d)*

As the electron beam is not deflected, then $F_m = F_e$ or $Bev = Ee$

or $v = \frac{E}{B}$ ...(i)

As the electron moves from cathode to anode, its potential energy at the cathode appears as its kinetic energy at the anode. If V is the potential difference between the anode and cathode, then potential energy of the electron at cathode $= eV$. Also, kinetic energy of the electron at anode $= \frac{1}{2}mv^2$. According to law of conservation of energy,

$$\frac{1}{2}mv^2 = eV \text{ or } v = \sqrt{\frac{2eV}{m}} \quad ...(ii)$$

From Eqs. (i) and (ii), we have

$$\sqrt{\frac{2eV}{m}} = \frac{E}{B} \text{ or } \frac{e}{m} = \frac{E^2}{2VB^2}$$

33 The magnetic force acting on a charged particle of charge $-2\,\mu C$ in a magnetic field of $2\,T$ acting in y-direction, when the particle velocity is $(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \times 10^6\ ms^{-1}$ is

(a) 8 N in z-direction **[CBSE AIPMT 2009]**
(b) 4 N in z-direction
(c) 8 N in y-direction
(d) 8 N in z-direction

Ans. *(a)*

Magnetic Lorentz force, $\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$

$= -2 \times 10^{-6}\{(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}}) \times 10^6 \times 2\hat{\mathbf{j}}\}$

$= -2 \times 10^{-6}[2 \times 2 \times 10^6 \hat{\mathbf{k}}]$

$= 8$ N along negative Z-axis

34 A particle of mass m, charge q and kinetic energy T enters a transverse uniform magnetic field of induction **B**. After 3 s, the kinetic energy of the particle will be **[CBSE AIPMT 2008]**

(a) $3T$ (b) $2T$
(c) T (d) $4T$

Ans. *(c)*

Magnetic field can never increase the energy of a charged particle so, its kinetic energy will remain same.

35 A beam of electrons passes undeflected through mutually perpendicular electric and magnetic fields. If the electric field is switched OFF and the same magnetic field is maintained, the electrons move **[CBSE AIPMT 2007]**

(a) in an elliptical orbit
(b) in a circular orbit
(c) along a parabolic path (d) along a straight line

Ans. *(b)*

If both electric and magnetic fields are present and are perpendicular to each other and the particle is moving perpendicular to both of them with $F_e = F_m$. In this situation $\mathbf{E} \neq 0$ and $\mathbf{B} \neq 0$ and $F_e + F_m = 0$.

But if electric field becomes zero, then only force due to magnetic field exists. And **E** is perpendicular to the **B** so the charge moves along a circle.

36 Under the influence of a uniform magnetic field a charged particle is moving in a circle of radius R with constant speed v. The time period of the motion **[CBSE AIPMT 2007]**

(a) depends on v and not on R
(b) depends on both R and v
(c) is independent of both R and v
(d) depends on R and not on v

Ans. *(c)*

When magnetic field is perpendicular to motion of charged particle, then particle performs circular motion.

So, centripetal force = magnetic force

i.e. $\frac{mv^2}{R} = Bqv$ or $R = \frac{mv}{Bq}$

Further, time period of the motion

$$T = \frac{2\pi R}{v} = \frac{2\pi\left(\frac{mv}{Bq}\right)}{v} \text{ or } T = \frac{2\pi m}{Bq}$$

37 When a charged particle moving with velocity **v** is subjected to a magnetic field of induction **B**, the force on it is non-zero. This implies that **[CBSE AIPMT 2006]**

(a) angle between **v** and **B** is necessarily 90°
(b) angle between **v** and **B** can have any value other than 90°
(c) angle between **v** and **B** can have any value other than zero and 180°
(d) ngle between **v** and **B** is either zero or 180°

Ans. *(c)*

When a charged particle q is moving in a uniform magnetic field **B** with velocity **v** such that angle between **v** and **B** is θ, then the charge q experiences a force which is given by

$F = q(\mathbf{v} \times \mathbf{B}) = qvB\sin\theta$

If $\theta = 0°$ or 180°, then $\sin\theta = 0$

$\therefore \quad F = qvB\sin\theta = 0$

Since, force on charged particle is non-zero, so angle between **v** and **B** can have any value other than 0° and 180°.

Note Force experienced by the charged particle is the Lorentz force.

38 An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to **[CBSE AIPMT 2005]**

(a) $\frac{B}{v}$ (b) $\frac{v}{B}$ (c) $\sqrt{\frac{v}{B}}$ (d) $\sqrt{\frac{B}{v}}$

Ans. *(c)*

The time period of electron moving in a circular orbit,

$$T = \frac{\text{Circumference of circular path}}{\text{Speed}} = \frac{2\pi r}{v}$$

Now, equivalent current due to flow of electron is given by

$$i = \frac{q}{T} = \frac{e}{(2\pi r/v)} = \frac{ev}{2\pi r} \quad [q = e]$$

Magnetic field at centre of circle

$$B = \frac{\mu_0 i}{2r} = \frac{\mu_0 ev}{4\pi r^2} \quad \left(i = \frac{eV}{2\pi r}\right)$$

$\Rightarrow \quad r \propto \sqrt{\frac{v}{B}}$

39 A charged particle moves through a magnetic field in a direction perpendicular to it. Then, the **[CBSE AIPMT 2003]**

(a) acceleration remains unchanged
(b) velocity remains unchanged
(c) speed of the particle remains unchanged
(d) direction of the particle remains unchanged

Ans. *(c)*

When a charged particle moves through a perpendicular magnetic field, then a magnetic force acts on it which changes the direction of particle but does not alter the magnitude of its velocity (i.e., speed).

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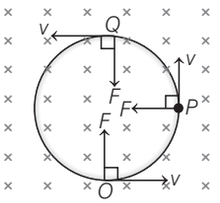


So, speed of charged particle remains unchanged i.e., of velocity magnitude remains constant.

Note If a charged particle moves at 45° to magnetic field, then path of the particle will be a helix whose circular part has radius according to relation, $r = \frac{mv \sin\theta}{qB}$.

40 A charge q moves in a region where electric field **E** and magnetic field **B** both exist, then the force on it is **[CBSE AIPMT 2002]**

(a) $q(\mathbf{v} \times \mathbf{B})$ (b) $q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$
(c) $q\mathbf{B} + q(\mathbf{B} \times \mathbf{v})$ (d) $q\mathbf{B} + q(\mathbf{E} \times \mathbf{v})$

Ans. *(b)*

If **E** is the electric field strength and **B** is the magnetic field strength and q is the charge on a particle, then electric force on the charge

$$\mathbf{F}_e = q\mathbf{E}$$

and magnetic force on the charge

$$\mathbf{F}_m = q(\mathbf{v} \times \mathbf{B})$$

The net force on the charge

$$\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = q\mathbf{E} + q(\mathbf{v} \times \mathbf{B})$$

Alternative

According to Lorentz force if a charged particle is in both electric field (**E**) and magnetic field (**B**), force is given by

$$\mathbf{F} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

41 A charged particle of charge q and mass m enters perpendicularly in a magnetic field **B**. Kinetic energy of the particle is E, then frequency of rotation is **[CBSE AIPMT 2001]**

(a) $\frac{qB}{m\pi}$ (b) $\frac{qB}{2\pi m}$ (c) $\frac{qBE}{2\pi m}$ (d) $\frac{qB}{2\pi E}$

Ans. *(b)*

Magnetic force = centripetal force

i.e. $qvB = \frac{mv^2}{r}$

or $qvB = mr\omega^2 \quad (v = r\omega)$

or $\omega^2 = \frac{qvB}{mr} = \frac{q(r\omega)B}{mr}$

Angular frequency, $\omega = \frac{qB}{m}$

If ν is the frequency of rotation, then

$$\omega = 2\pi\nu \Rightarrow \nu = \frac{\omega}{2\pi}$$

$$\therefore \quad \nu = \frac{qB}{2\pi m}$$

Note In the resultant expression $\frac{q}{m}$ is known as specific charge. It is sometimes denoted by α. So, in terms of α, the above formula can be written as

$$\omega = B\alpha \quad \text{and} \quad \nu = \frac{B\alpha}{2\pi}$$

42 A positively charged particle moving due east enters a region of uniform magnetic field directed vertically upwards. The particle will **[CBSE AIPMT 1997]**

(a) continue to move due East
(b) move in a circular orbit with its speed unchanged
(c) move in a circular orbit with its speed increased
(d) gets deflected vertically upwards

Ans. *(b)*

According to the question, the magnetic field is perpendicular to the direction of motion of charged particle.

Force on the charged particle is given by

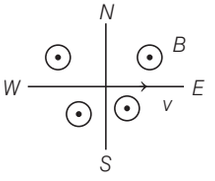
$F = qvB \sin\theta = q(\mathbf{v} \times \mathbf{B})$

where, q = charge on charged particle

v = velocity of charged particle

B = magnetic field

θ = angle between **v** and **B** = 90°



According to Fleming's left hand rule, the force acts perpendicular to the velocity of the particle. This force in magnitude remains same but the direction of charged particle goes on changing and always perpendicular to the velocity of the particle, so the particle will move in a circular orbit. The magnetic force does not make any change in its kinetic energy which implies that speed is constant or unchanged.

43 A beam of electrons is moving with constant velocity in a region having simultaneous perpendicular electric and magnetic fields of strength 20 Vm^{-1} and 0.5 T, respectively at right angles to the direction of motion of the electrons. Then, the velocity of electrons must be **[CBSE AIPMT 1996]**

(a) 8 m/s (b) 20 m/s
(c) 40 m/s (d) $\frac{1}{40}$ m/s

Ans. *(c)*

According to Lorentz force,

$$\mathbf{F}_{net} = q[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$$

When **v**, **E** and **B** are mutually perpendicular to each other, in this situation if **E** and **B** are such that $\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = 0$, then acceleration in the particle, $\mathbf{a} = \frac{\mathbf{F}}{m} = 0$. It means particle will pass undeflected.

Here, $F_e = F_m$

So, $qE = qvB \quad \begin{bmatrix} F_e = qE \\ F_M = qvB \end{bmatrix}$

or $v = \frac{E}{B}$

Given, $E = 20\ Vm^{-1}$

$B = 0.5\ T$

$\therefore \quad v = \frac{20}{0.5} = 40\ m/s$

44 A 10 eV electron is circulating in a plane at right angle to a uniform field of magnetic induction 10^{-4} Wb/m^2 (=1.0 gauss). The orbital radius of the electron is **[CBSE AIPMT 1996]**

(a) 12 cm (b) 16 cm
(c) 11 cm (d) 18 cm

Ans. *(c)*

If charged particle is moving perpendicular to the direction of **B**, it experiences a maximum force which acts perpendicular to the direction of **B** as well as **v**. Hence, this force will provide the required centripetal force and the charged particle will describe a circular path in the magnetic field of radius r and is given by

$$\frac{mv^2}{r} = qvB$$

Now, KE of electron = 10 eV

$$\Rightarrow \quad \frac{1}{2}mv^2 = 10\ eV$$

$$\therefore \quad \frac{1}{2} \times (9.1 \times 10^{-31})v^2 = 10 \times 1.6 \times 10^{-19}$$

$$\Rightarrow \quad v^2 = \frac{2 \times 10 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$$\Rightarrow \quad v^2 = 3.52 \times 10^{12}$$

or $v = 1.88 \times 10^6$ m

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Now, radius of circular path,

$$r = \frac{mv}{qB} = \frac{9.1\times10^{-31}\times1.88\times10^{6}}{1.6\times10^{-19}\times10^{-4}} = 11\text{ cm}$$

45 An electron enters a region where magnetic field (B) and electric field (E) are mutually perpendicular, then **[CBSE AIPMT 1994]**

(a) it will always move in the direction of B

(b) it will always move in the direction of E

(c) it always possess circular motion

(d) it can go undeflected also

Ans. *(d)*

The force experienced by a charged particle moving in space where both electric and magnetic fields exist is called Lorentz force.

Due to both electric and magnetic fields, the total force experienced by the charged particle will be given by,

$$\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = q\mathbf{E} + q(\mathbf{v}\times\mathbf{B})$$
$$= q(\mathbf{E} + \mathbf{v}\times\mathbf{B})$$

When $\mathbf{v}$, $\mathbf{E}$ and $\mathbf{B}$ are mutually perpendicular to each other. In this situation, if $\mathbf{E}$ and $\mathbf{B}$ are such that $\mathbf{F} = \mathbf{F}_e + \mathbf{F}_m = 0$, then acceleration in the particle, $\mathbf{a} = \frac{\mathbf{F}}{m} = 0$.

It means particle will go undeflected.

46 A charge moving with velocity v in x-direction is subjected to a field of magnetic induction in negative x-direction. As a result, the charge will **[CBSE AIPMT 1993]**

(a) remain unaffected

(b) start moving in a circular y-z plane

(c) retard along x-axis

(d) move along a helical path around x-axis

Ans. *(a)*

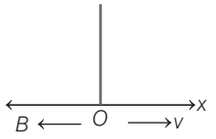
Force on a charged particle in the magnetic field is

$$|\mathbf{F}| = q|\mathbf{v}\times\mathbf{B}| \quad \text{or} \quad F = qvB\sin\theta$$

when angle between velocity v and magnetic induction B is 180° or 0°, then

$$F = qvB\sin180° = 0$$

[as $\sin180° \text{ or } \sin0° = 0$]



So, the charged particle remains unaffected.

47 A uniform magnetic field acts right angles to the direction of motion of electrons. As a result, the electron moves in a circular path of radius 2 cm. If the speed of electrons is doubled, then the radius of the circular path will be **[CBSE AIPMT 1991]**

(a) 2.0 cm (b) 0.5 cm

(c) 4.0 cm (d) 1.0 cm

Ans. *(c)*

The force F on the charged particle due to external magnetic field provides the required centripetal force ($= mv^2/r$) necessary for motion along the circular path of radius r.

So $qvB = \frac{mv^2}{r}$ or $r = \frac{mv}{qB}$

$$\therefore \quad r \propto v \qquad \left[\frac{m}{qB} = \text{constant}\right]$$

As v is doubled, the radius also becomes double. Hence, radius $= 2\times2 = 4$ cm.

48 A deutron of kinetic energy 50 keV is describing a circular orbit of radius 0.5 m in a plane perpendicular to magnetic field B. The kinetic energy of the proton that describes a circular orbit of radius 0.5 m in the same plane with the same magnetic field B is **[CBSE AIPMT 1991]**

(a) 25 keV (b) 50 keV

(c) 200 keV (d) 100 keV

Ans. *(d)*

When charged particle move on circular path, the force F on the charged particle due to magnetic field provides the required centripetal force ($= mv^2/r$) necessary for motion along the circular path.

So, $\frac{mv^2}{r} = qvB$

where, m = mass of particle

v = velocity of particle

q = charge on particle

B = external magnetic field

r = radius of circular path

$mv^2 = Bqvr$

$$\therefore \text{ Kinetic energy } E_K = \frac{1}{2}mv^2 = \frac{1}{2}Bqvr$$
$$= Bq\cdot\frac{r}{2}\frac{Bqr}{m} = \frac{B^2q^2r^2}{2m}$$

For deutron, $E_1 = \frac{B^2q^2r^2}{2\times(2m)}$ (mass $= 2m$)

For proton, $E_2 = \frac{B^2q^2r^2}{2m}$ (mass $= m$)

$$\therefore \quad \frac{E_1}{E_2} = \frac{1}{2} \Rightarrow \frac{50\text{ keV}}{E_2} = \frac{1}{2}$$

or $E_2 = 100$ keV

TOPIC 3

Force and Torque on Current Carrying Conductor

49 A metallic rod of mass per unit length 0.5 kg m^{-1} is lying horizontally on a smooth inclined plane which makes an angle of 30° with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25 T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is **[NEET 2018]**

(a) 14.76 A (b) 5.98 A

(c) 7.14 A (d) 11.32 A

Ans. *(d)*

Key Concept *Firstly, make a free body diagram of the system and indicate the magnitude and direction of all the forces acting on the body. Then, choose any two mutually perpendicular axes say X and Y in the plane of forces in case of coplanar forces.*

As, the system is in equilibrium,

$$\Sigma F_x = 0$$

or $mg\sin\theta = F\cos\theta$ ...(i)

where, F is the magnitude of force experienced by the rod when placed in a magnetic field and current I is flowing through it.

But the force experienced by the given rod in a uniform magnetic field is

$$F = ILB$$

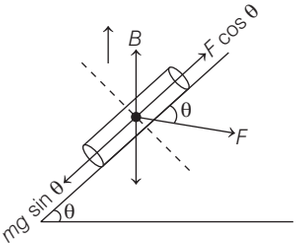
$\therefore$ Eq. (i) becomes,

$mg\sin\theta = ILB\cos\theta$

$$\Rightarrow \quad I = \frac{mg\sin\theta}{LB\cos\theta} = \frac{mg}{LB}\tan\theta$$

$$I = \left(\frac{m}{L}\right)\frac{g\tan\theta}{B} \qquad \text{...(ii)}$$

According to the question,



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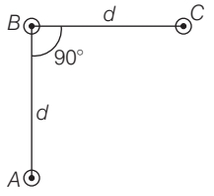
Here, $\frac{m}{L} = 0.5\ \text{kg m}^{-1}$, $g = 9.8\ \text{ms}^{-2}$,
$\theta = 30°$, $B = 0.25$ T
Substituting the given values in Eq. (ii), we get

$$I = \frac{0.5 \times 9.8}{0.25} \tan 30°$$
$$= \frac{0.5 \times 9.8}{0.25} \times \frac{1}{\sqrt{3}}$$
$$= 11.32 \text{ A}$$

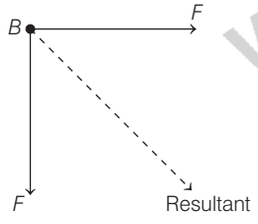
50 An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current I along the same direction is shown in figure. Magnitude of force per unit length on the middle wire B is given by **[NEET 2017]**



(a) $\frac{\mu_0 i^2}{2\pi d}$ (b) $\frac{2\mu_0 i^2}{\pi d}$
(c) $\frac{\sqrt{2}\mu_0 i^2}{\pi d}$ (d) $\frac{\mu_0 i^2}{\sqrt{2}\,\pi d}$

Ans. ***(d)***

As force on wire B due to A and C are attractive, so we have following condition



$$F = \frac{\mu_0 I^2}{2\pi d}$$

Resultant force on B

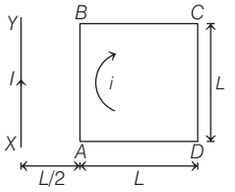
$$= \sqrt{F_1^2 + F_2^2} = \sqrt{2}\,F = \sqrt{2} \times \frac{\mu_0 I^2}{2\pi d} = \frac{\mu_0 I^2}{\sqrt{2}\pi d}$$

51 A square loop $ABCD$ carrying a current i, is placed near and coplanar with a long straight conductor XY carrying a current I, the net force on the loop will be **[NEET 2016]**

(a) $\frac{\mu_0 Ii}{2\pi}$ (b) $\frac{2\mu_0 IiL}{3\pi}$
(c) $\frac{\mu_0 IiL}{2\pi}$ (d) $\frac{2\mu_0 Ii}{3\pi}$

Ans. ***(d)***

Consider the given figure,



From the above figure, it can be seen that the direction of currents in a long straight conductor XY and arm AB of a square loop $ABCD$ are in the same direction. So, there exist a force of attraction between the two, which will be experienced by F_{BA} as

$$F_{BA} = \frac{\mu_0 IiL}{2\pi\left(\frac{L}{2}\right)}$$

In the case of XY and arm CD, the direction of currents are in the opposite direction. So, there exist a force of repulsion which will be experienced by CD as $F_{CD} = \frac{\mu_0 IiL}{2\pi\left(\frac{3L}{2}\right)}$

Therefore, net force on the loop $ABCD$ will be

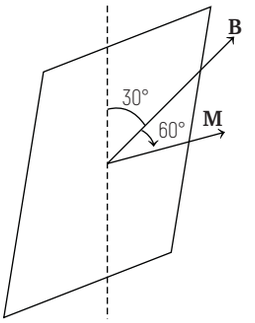
$$F_{\text{loop}} = F_{BA} - F_{CD} = \frac{\mu_0 IiL}{2\pi}\left[\frac{1}{(L/2)} - \frac{1}{(3L/2)}\right]$$
$$F_{\text{loop}} = \frac{2\mu_0 Il}{3\pi}$$

52 A rectangular coil of length 0.12 m and width 0.1 m having 50 turns of wire is suspended vertically in a uniform magnetic field of strength 0.2 Wb/m^2. The coil carries a current of 2 A. If the plane of the coil is inclined at an angle of 30° with the direction of the field, the torque required to keep the coil in stable equilibrium will be **[CBSE AIPMT 2015]**

(a) 0.15 Nm (b) 0.20 Nm
(c) 0.24 Nm (d) 0.12 Nm

Ans. ***(b)***

Given, $N = 50$
$B = 0.2\ \text{Wb/m}^2$, $I = 2$ A
$\theta = 60°$, $A = 0.12 \times 0.1 = 0.012\ \text{m}^2$



Thus, torque required to keep the coil in stable equilibrium, i.e.

$$\tau = NIAB \sin\theta$$
$$= 50 \times 2 \times 0.012 \times 0.2 \times \sin 60°$$
$$= 50 \times 2 \times 0.12 \times 0.2 \times \frac{\sqrt{3}}{2} = 0.20$$

Nm

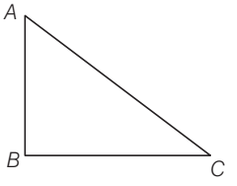
53 A current loop in a magnetic field **[NEET 2013]**

(a) experiences a torque whether the field is uniform or non-uniform in all orientations
(b) can be in equilibrium in one orientation
(c) can be in equilibrium in two orientations, both the equilibrium states are unstable
(d) can be in equilibrium in two orientations, one stable while other is unstable

Ans. ***(d)***

For parallel, **M** is stable and for antiparallel, it is unstable.

54. A current carrying closed loop in the form of a right angled isosceles Δ ABC is placed in a uniform magnetic field acting along AB. If the magnetic force on the arm BC is **F**, the force on the arm AC is **[CBSE AIPMT 2011]**



(a) –**F** (b) **F**
(c) $\sqrt{2}$F (d) $-\sqrt{2}$F

Ans. ***(a)***

Force on AB is given by, $\mathbf{F}_{AB} = 0$

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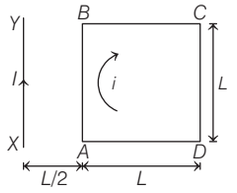
According to the question,



$$\mathbf{F}_{AB} = 0$$
$$\Rightarrow \quad \mathbf{F}_{AB} + \mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$
$$\mathbf{F}_{BC} + \mathbf{F}_{CA} = 0$$
$$\mathbf{F}_{CA} = -\mathbf{F}_{BC} = -\mathbf{F}$$

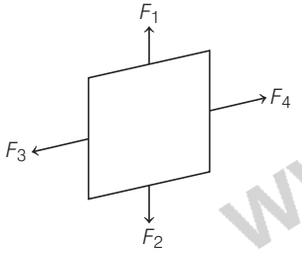
55 A square current carrying loop is suspended in a uniform magnetic field acting in the plane of the loop. If the force on one arm of the loop is **F**, the net force on the remaining three arms of the loop is **[CBSE AIPMT 2010]**

(a) 3F (b) –F (c) –3F (d) F

Ans. ***(b)***

When a current carrying loop is placed in a magnetic field, the coil experiences a torque given by $\tau = NBi\,A\sin\theta$. Torque is maximum when $\theta = 90°$, i.e., the plane of the coil is parallel to the field.

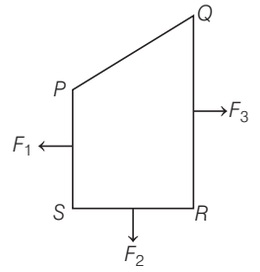
$$\tau_{max} = NBiA$$



Forces $\mathbf{F}_1$ and $\mathbf{F}_2$ acting on the coil are equal in magnitude and opposite in direction. As the forces $\mathbf{F}_1$ and $\mathbf{F}_2$ have the same line of action, their resultant effect on the coil is zero.

The two forces $\mathbf{F}_3$ and $\mathbf{F}_4$ are equal in magnitude and opposite in direction. As the two forces have different lines of action, they constitute a torque. Thus, if the force on one arc of the loop is **F**, the net force on the remaining three arms of the loop is –**F**.

56 A closed loop *PQRS* carrying a current is placed in a uniform magnetic field. If the magnetic forces on segments *PS*, *SR* and *RQ* are F_1, F_2 and F_3 respectively and are in the plane of the paper and along the directions shown in figure, the force on the segment *QP* is **[CBSE AIPMT 2008]**



(a) $F_3 - F_1 - F_2$

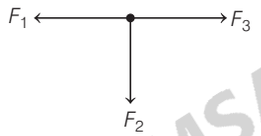
(b) $\sqrt{(F_3 - F_1)^2 + F_2^2}$

(c) $\sqrt{(F_3 - F_1)^2 - F_2^2}$

(d) $F_3 - F_1 + F_2$

Ans. ***(b)***

As the net force on closed loop is equal to zero. So, force on *QP* will be equal and opposite to sum of forces on other 3 sides.



So, from vector laws,

$$F_{QP} = \sqrt{(F_3 - F_1)^2 + F_2^2}$$

57 A coil in the shape of an equilateral triangle of side *l* is suspended between the pole pieces of a permanent magnet such that **F** is in plane of the coil. If due to a current *i* in the triangle a torque τ acts on it, the side *l* of the triangle is **[CBSE AIPMT 2005]**

(a) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)^{1/2}$ (b) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{Bi}\right)$

(c) $2\left(\frac{\tau}{\sqrt{3}Bi}\right)^{1/2}$ (d) $\frac{1}{\sqrt{3}}\frac{\tau}{Bi}$

Ans. ***(c)***

Torque acting on equilateral triangle in a magnetic field **B** is

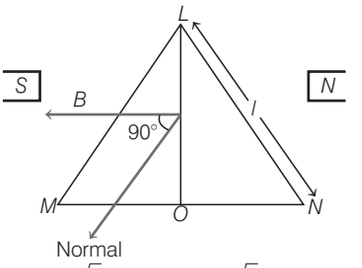
$$\tau = \mathbf{M} \times \mathbf{B},\ \tau = iAB\sin\theta \qquad [iA = \mathbf{M}]$$

Area of ΔLMN

$$A = \frac{\sqrt{3}}{4}l^2 \text{ and } \theta = 90°$$

[l = sides of triangle]

Substituting the given values in the expression for torque, we have



$$\tau = i \times \frac{\sqrt{3}}{4}l^2\ B\sin 90° = \frac{\sqrt{3}}{4}il^2\ B$$

($\because \sin 90° = 1$)

Hence, $$l = 2\left(\frac{\tau}{\sqrt{3}\,Bi}\right)^{1/2}$$

58 Current is flowing in a coil of area *A* and number of turns *N*, then magnetic moment of the coil, *M* is equal to **[CBSE AIPMT 2001]**

(a) NiA (b) $\frac{Ni}{A}$

(c) $\frac{Ni}{\sqrt{A}}$ (d) N^2Ai

Ans. ***(a)***

If there are *N* turns in a coil, *i* is the current flowing and *A* is the area of the coil, then magnetic dipole moment or simply magnetic moment of the coil is

$$M = NiA$$

As we know when velocity of charged particle entering to magnetic field region is perpendicular to **B**, then it follows circular path.

59 Two long parallel wires are at a distance of 1 m. Both of them carry 1A of current. The force of attraction per unit length between the two wires is **[CBSE AIPMT 1998]**

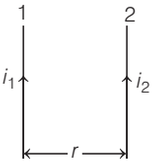
(a) 2×10^{-7} N/m (b) 2×10^{-8} N/m

(c) 5×10^{-8} N/m (d) 10^{-7} N/m

Ans. ***(a)***

Magnetic force between parallel wires per unit length is given by

$$\frac{F}{l} = \frac{\mu_0}{2\pi} \times \frac{i_1 i_2}{r}$$



where, i_1 and i_2 are the currents in wires 1 and 2 respectively and *r* is the distance between them. Since, it is given that between two wires there is a force of

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attraction, so, the direction of currents in both will be the same.

Given, $i_1 = i_2 = 1\,A$, $r = 1\,m$,

$\mu_0 = 4\pi \times 10^{-7}$ T-m/A

$\therefore \quad \frac{F}{l} = \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{1 \times 1}{1} = 2 \times 10^{-7}$ N/m

Note When current is in same direction in both the wires there will be attraction and if current in opposite direction there is repulsion.

60 A straight wire of length 0.5 m and carrying a current of 1.2 A is placed in uniform magnetic field of induction 2 T. The magnetic field is perpendicular to the length of the wire. The force on the wire is **[CBSE AIPMT 1992]**

(a) 2.4 N (b) 1.2 N (c) 3.0 N (d) 2.0 N

Ans. *(b)*

Force on a current carrying conductor placed in a magnetic field is given by

$$F = i(\mathbf{l} \times \mathbf{B}) = il\,B \sin\theta$$

where, θ = angle between current elements and magnetic field.

If linear conductor carrying current is placed perpendicular to the direction of magnetic field, ($\theta = 90°$) it will experience maximum force.

i.e., $F_{max} = ilB$

Given, $i = 1.2$ A, $l = 0.5$ m and $B = 2$ T

$\therefore \quad F = 2 \times 1.2 \times 0.5 = 1.2$ N

61 A current carrying coil is subjected to a uniform magnetic field. The coil will orient so that its plane becomes **[CBSE AIPMT 1988]**

(a) inclined at 45° to the magnetic field

(b) inclined at any arbitrary angle to the magnetic field

(c) parallel to the magnetic field

(d) perpendicular to magnetic field

Ans. *(c)*

The coil must orient so that its magnetic moment becomes parallel to the field. So that the magnetic force on the coil is zero.

TOPIC 4
Moving Coil Galvanometer

62 Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is **[NEET 2018]**

(a) 250 Ω (b) 25 Ω

(c) 40 Ω (d) 500 Ω

Ans. *(a)*

Current sensitivity of a moving coil galvanometer is the deflection (θ) per unit current (I) flowing through it, i.e.

$$I_S = \frac{\theta}{I} = \frac{NAB}{k} \qquad ...(i)$$

where, N = number of turns in the coil,

A = Area of each turn of coil,

B = magnetic field

k = restoring torque per unit twist of the fibre strip.

Similarly, voltage sensitivity is the deflection per unit voltage, i.e.

$$V_S = \frac{\theta}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} = \frac{NAB}{kR_G} \qquad ...(ii)$$

where, R_G is the resistance of the galvanometer.

From Eqs. (i) and (ii), we get

$$R_G = \frac{I_S}{V_S} \qquad ...(iii)$$

Here, $I_S = 5$ div/mA $= 5 \times 10^{-3}$ div/A

and $V_S = 20$ div/V

Substituting the given values in Eq. (iii), we get

$$R_G = \frac{5 \times 10^3}{20} = 250$$

$\therefore$ The resistance of the galvanometer is 250 Ω.

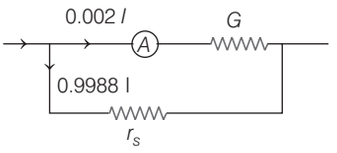
63 In an ammeter 0.2% of main current passes through the galvanometer. If resistance of galvanometer is G, the resistance of ammeter will be **[CBSE AIPMT 2014]**

(a) $\frac{1}{499}G$ (b) $\frac{499}{500}G$

(c) $\frac{1}{500}G$ (d) $\frac{500}{499}G$

Ans. *(c)*

For ammeter,



$0.002I \times G = 0.998I \times r_s$

$$r_s = \frac{0.002}{0.998}G$$

$$\Rightarrow \quad r_s = 0.002004\,G = \frac{1}{499} \times G$$

Equivalent resistance of ammeter,

$$\frac{1}{R} = \frac{1}{G} + \frac{1}{r_s}$$

$$\therefore \quad \frac{1}{R} = \frac{1}{G} + \frac{1}{G/499} \Rightarrow R = \frac{G}{500}$$

64 A millivoltmeter of 25 mV range is to be converted into an ammeter of 25 A range. The value (in ohm) of necessary shunt will be **[CBSE AIPMT 2012]**

(a) 0.001 (b) 0.01

(c) 1 (d) 0.05

Ans. *(a)*

The full scale deflection current

$$i_g = \frac{25\,mV}{G}\,A$$

where, G is the resistance of the meter.

The value of shunt required for converting it into ammeter of range 25 A is $S = \frac{i_g G}{i - i_g} \Rightarrow S = i_g \frac{G}{i}$ (as $i >> i_g$)

So that,

$$S \approx \frac{25\,mV}{G} \cdot \frac{G}{i} = \frac{25\,mV}{25} = 0.001\,\Omega$$

65 The resistance of an ammeter is 13 Ω and its scale is graduated for a current upto 100 A. After an additional shunt has been connected to this ammeter it becomes possible to measure currents upto 750 A by this meter. The value of shunt resistance is **[CBSE AIPMT 2007]**

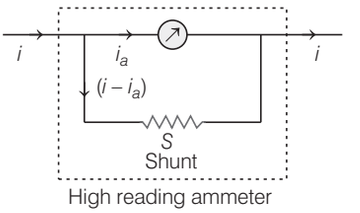
(a) 20 Ω (b) 2 Ω (c) 0.2 Ω (d) 2 kΩ

Ans. *(b)*

Let i_a be the current flowing through ammeter and i be the total current. So, a current $i - i_a$ will flow through shunt resistance.

Potential difference across ammeter and shunt resistance is same.

i.e. $i_a \times R = (i - i_a) \times S$



or $\quad S = \frac{i_a R}{i - i_a} \qquad ...(i)$

Given, $i_a = 100\,A, i = 750\,A, R = 13\,\Omega$

Hence, $S = \frac{100 \times 13}{750 - 100} = 2\,\Omega$

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19

Magnetism and Matter

TOPIC 1
Bar Magnet and Magnetic Dipole

01 A uniform conducting wire of length $12a$ and resistance R is wound up as a current (I) carrying coil in the shape of

1. an equilateral triangle of side a.
2. a square of side a.

The magnetic dipole moments of the coil in each case respectively are **[NEET 2021]**

(a) $\sqrt{3}Ia^2$ and $3Ia^2$ (b) $3Ia^2$ and Ia^2
(c) $3Ia^2$ and $4Ia^2$ (d) $4Ia^2$ and $3Ia^2$

Ans. *(a)*

Given, the length of a uniform conducting wire, $L = 12a$

The resistance of a uniform conducting wire $= R$

We know that, magnetic dipole moment, $M = nIA$

Here, I is the current in the loop,

A is the area of the coil,

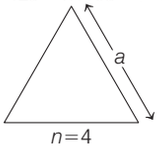
n is the number of loops.

For case (1):

An equilateral triangle of side a.

Total wire length $= n \times$ Perimeter of the triangle

$$12a = n \times 3a \Rightarrow n = 4$$



Area of the triangle, $A = \frac{\sqrt{3}}{4}a^2$

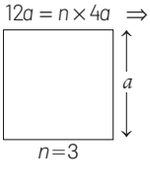
Magnetic dipole moment, $M = nIA$

$$\Rightarrow \quad M = 4I \times \frac{\sqrt{3}}{4}a^2 \Rightarrow M = \sqrt{3}Ia^2$$

For case (2) : A square of side a.

Total wire length $= n \times$ Perimeter of the square

$$12a = n \times 4a \Rightarrow n = 3$$



Area of the square loop, $A = a^2$

Magnetic dipole moment,

$$M = nIA \Rightarrow M = 3Ia^2$$

02 A wire of length L metre carrying a current of I ampere is bent in the form of a circle. Its magnetic moment is **[NEET (Oct.) 2020]**

(a) $IL^2/4\text{Am}^2$ (b) $I\pi L^2/4\text{ Am}^2$
(c) $2IL^2/\pi\text{ Am}^2$ (d) $IL^2/4\pi\text{ Am}^2$

Ans. *(d)*

When wire of length L is bent in the form of a circle of radius R, then

$$L = 2\pi R$$

$$\Rightarrow \quad R = \frac{L}{2\pi}$$

$\therefore$ Magnetic moment, $M = IA = I(\pi R^2)$

$$= I \cdot \pi\left(\frac{L}{2\pi}\right)^2 = \frac{I\pi L^2}{4\pi^2} = \frac{IL^2}{4\pi}\text{ Am}^2$$

03 A 250-turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180° against the torque is **[NEET 2017]**

(a) 9.1 μJ (b) 4.55 μJ
(c) 2.3 μJ (d) 1.5 μJ

Ans. *(a)*

Work done for rotating the coil

$$W = MB(\cos\theta_1 - \cos\theta_2)$$

where, M = magnetic moment

B = magnetic field

Given, $\theta_1 = 0°, \theta_2 = 180°$

$$\Rightarrow \quad W = MB(\cos 0° - \cos 180°)$$

$$= 2MB = 2 \times NIA \times B$$

$$= 2 \times 250 \times 85 \times 10^{-6} \times (2.1 \times 1.25 \times 10^{-4}) \times 0.85$$

$$= 9.48 \times 10^{-6}\text{ J}$$

$$\approx 9.5 \times 10^{-6}\text{ J} = 9.5\,\mu\text{J}$$

The closest option is (a).

04 A bar magnet is hung by a thin cotton thread in a uniform horizontal magnetic field and is in equilibrium state. The energy required to rotate it by 60° is W. Now the torque required to keep the magnet in this new position is **[NEET 2016]**

(a) $\frac{W}{\sqrt{3}}$ (b) $\sqrt{3}W$
(c) $\frac{\sqrt{3}W}{2}$ (d) $\frac{2W}{\sqrt{3}}$

Ans. *(b)*

$\because$ Work done in rotating the magnet

$$W = MB(\cos\theta_0 - \cos\theta)$$

Where, M = magnetic moment of the magnet

B = magnetic field

$$W = MB(\cos 0° - \cos 60°)$$

$$= MB\left(1 - \frac{1}{2}\right) = \frac{MB}{2}$$

$$\therefore \quad MB = 2W \qquad \ldots(i)$$

Torque on a magnet in this position is given by,

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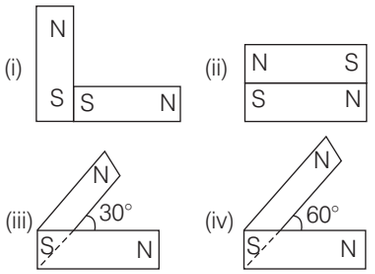
$$\tau = \mathbf{M}\times\mathbf{B}$$
$$= MB\cdot\sin\theta = 2W\cdot\sin 60°$$
[from Eq. (i)]
$$= 2W\frac{\sqrt{3}}{2} = W\sqrt{3}$$

05 Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment M. Which configuration has highest net magnetic dipole moment? **[CBSE AIPMT 2014]**



(a) (i) (b) (ii)
(c) (iii) (d) (iv)

Ans. *(c)*

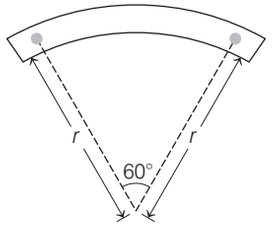
Magnetic moment is from S to N

So, $M_{net} = \sqrt{M^2 + M^2 + 2M^2\cos\theta}$

M_{net} will be maximum if $\cos\theta$ is maximum. $\cos\theta$ will be maximum when θ will be minimum.

So, at $\theta = 30°$, M_{net} will be maximum.

06 A bar magnet of length l and magnetic dipole moment M is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be **[NEET 2013]**



(a) M (b) $\frac{3}{\pi}M$
(c) $\frac{2}{\pi}M$ (d) $\frac{M}{2}$

Ans. *(b)*

The magnetic moment, $M = ml$
(m = pole strength, l = length of magnet)

According to question,
$$l = \frac{\pi}{3}\times r$$
So, $$r = \frac{3l}{\pi}$$

New magnetic moment, $M' = m\times r$
$$= m\times\frac{3l}{\pi} = \frac{3}{\pi}\cdot ml = \frac{3M}{\pi}$$

07 A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It **[CBSE AIPMT 2012]**
(a) will become rigid showing no movement
(b) will stay in any position
(c) will stay in North-South direction only
(d) will stay in East-West direction only

Ans. *(c)*

It will stay in any position at geomagnetic North and South poles.

08 A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6\times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is **[CBSE AIPMT 2009]**

(a) 0.6 J (b) 12 J
(c) 6 J (d) 2 J

Ans. *(c)*

When magnetic dipole is rotated from initial position θ_1 to final position θ_2, then work done $= MB(\cos\theta_1 - \cos\theta_2)$

Given, $\theta_1 = 0°, \theta_2 = 60°$

Magnetic moment, $M = 2\times 10^4$ J/T

Magnetic field, $B = 6\times 10^{-4}$ T

So, $W = MB\left(1-\frac{1}{2}\right)$ [$\because \cos 0° = 1$ and $\cos 60° = 1/2$]
$$= \frac{2\times 10^4\times 6\times 10^{-4}}{2} = 6\text{ J}$$

09 A charged particle (charge q) is moving in a circle of radius R with uniform speed v. The associated magnetic moment μ is given by **[CBSE AIPMT 2007]**

(a) $\frac{qvR}{2}$ (b) qvR^2 (c) $\frac{qvR^2}{2}$ (d) qvR

Ans. *(a)*

As revolving charge is equivalent to a current, so
$$= qf = q\times\frac{\omega}{2\pi}$$

But, $$\omega = \frac{v}{R}$$

where, R is radius of circle and v is uniform speed of charged particle.

Therefore, $i = \frac{qv}{2\pi R}$

Now, magnetic moment associated with charged particle is given by
$$\mu = iA = i\times\pi R^2$$
or $$\mu = \frac{qv}{2\pi R}\times\pi R^2 = \frac{1}{2}qvR$$

Alternative

Current produced due to circular motion of charge q is given by
$$i = \frac{q}{T}$$ [T = Time period of revolution]

Now $$T = \frac{2\pi R}{v}$$

So, $$i = \frac{q}{2\pi R}\times v$$

Now, magnetic moment (μ) is given by
$$\mu = iA$$
So $\mu = \frac{qv}{2\pi R}\times\pi R^2 \Rightarrow \mu = \frac{qvR}{2}$

10 A bar magnet of magnetic moment $\mathbf{M}$ is placed in a magnetic field of induction $\mathbf{B}$. The torque exerted on it is **[CBSE AIPMT 1999]**

(a) $\mathbf{M}\cdot\mathbf{B}$ (b) $-\mathbf{M}\cdot\mathbf{B}$
(c) $\mathbf{M}\times\mathbf{B}$ (d) $-\mathbf{M}\times\mathbf{B}$

Ans. *(c)*

When a bar magnet is placed in an external magnetic field $\mathbf{B}$, a magnetic torque τ acts on it, which is given by
$\tau = \mathbf{M}\times\mathbf{B} = |\mathbf{M}|\times|\mathbf{B}|\sin\theta$
(θ = angle between $\mathbf{M}$ and $\mathbf{B}$)

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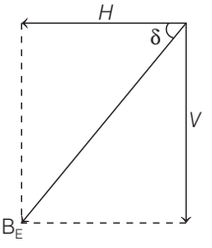
TOPIC 2
Earth Magnetism

11 The relations amongst the three elements earth's magnetic field, namely horizontal component H, vertical component V and dip δ are, (B_E = total magnetic field)
[NEET (Odisha) 2019]

(a) $V = B_E \tan\delta, H = B_E$
(b) $V = B_E \sin\delta, H = B_E \cos\delta$
(c) $V = B_E \cos\delta, H = B_E \sin\delta$
(d) $V = B_E, H = Be_E \tan\delta$

Ans. *(b)*

Let B_E be the net magnetic field at same point. H and V be the horizontal and vertical components of B_E. Let δ be the angle of dip, which is the angle between direction of earth's magnetic field B_E and horizontal line in the magnetic meridian.



Thus, from figure, we can see that
$H = B_E \cos\delta$ and $V = B_E \sin\delta$

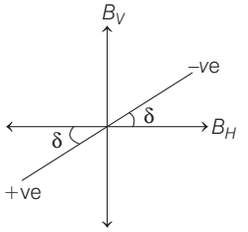
12 At a point A on the earth's surface the angle of dip, $\delta = +25°$.
At a point B on the earth's surface the angle of dip, $\delta = -25°$.
We can interpret that
[NEET (National) 2019]

(a) A is located in the southern hemisphere and B is located in the northern hemisphere.
(b) A is located in the northern hemisphere and B is located in the southern hemisphere.
(c) A and B are both located in the southern hemisphere.
(d) A and B are both located in the northern hemisphere.

Ans. *(b)*

The angle of dip (δ) is the angle between the horizontal component of earth's magnetic field and the total magnetic field of the earth. Its value is different at different places. It is zero at equator, as the dip neddle becomes parallel to horizontal component. It varies from $-90°$ in South pole to $+90°$ in the North pole.

This means the values δ is positive in northern hemisphere and is negative in southern hemisphere.



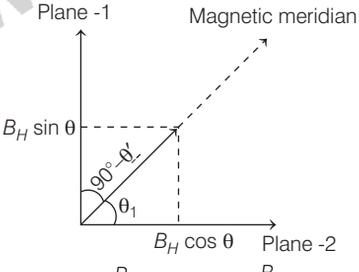
$\therefore$ For point A, $\delta = +25°$,
So, A lies in the northern hemisphere.
Similarly, for B, $\delta = -25°$, so
B lies in the southern hemisphere.

13 If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is given by **[NEET 2017]**

(a) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$
(b) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$
(c) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$
(d) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$

Ans. *(a)*

Let the B_H and B_V be the horizontal and vertical component of earth's magnetic field B.



$$\tan\theta = \frac{B_V}{B_H} \Rightarrow \cot\theta = \frac{B_H}{B_V} \quad ...(i)$$

Let, plane 1 and 2 are mutually perpendicular planes making angle θ and $(90° - \theta)$ with magnetic meridian. The vertical component of earth of earth's magnetic field remain same in two plane but effective horizontal components in the two planes is given by

$$B_1 = B_H \cos\theta' \quad ...(ii)$$

and $$B_2 = B_H \sin\theta' \quad ...(iii)$$

Then, $$\tan\theta_1 = \frac{B_V}{B_1} = \frac{B_V}{B_H \cos\theta'}$$

$$\cot\theta_1 = \frac{B_H \cos\theta'}{B_V} \quad ...(iv)$$

Similarly,

$$\Rightarrow \quad \tan\theta_2 = \frac{B_V}{B_2} = \frac{B_V}{B_H \sin\theta'}$$

$$\Rightarrow \quad \cot\theta_2 = \frac{B_H \sin\theta'}{B_V} \quad ...(v)$$

From Eq. (iv) and Eq. (v)

$$\Rightarrow \quad \cot^2\theta_1 + \cot^2\theta_2 = \frac{B_H^2 \cos^2\theta'}{B_V^2} + \frac{B_H^2 \sin^2\theta'}{B_V^2}$$

$$\Rightarrow \quad \cot^2\theta_1 + \cot^2\theta_2 = \frac{B_H^2}{B_V^2}(\cos^2\theta' + \sin^2\theta')$$

$$\Rightarrow \quad \cot^2\theta_1 + \cot^2\theta_2 = \cot^2\theta$$

14 A vibration magnetometer placed in magnetic meridian has a small bar magnet. The magnet executes oscillations with a time period of 2 s in the earth's horizontal magnetic field of 24 μT. When a horizontal field of 18 μT is produced opposite to the earth's field by placing a current carrying wire, the new time period of magnet will be **[CBSE AIPMT 2010]**

(a) 1 s (b) 2 s
(c) 3 s (d) 4 s

Ans. *(b)*

Problem Solving Strategy Find out the relation of time period with the earth's horizontal magnetic field and then compare it for the two given cases.
Time period in vibration magnetometer is given by

$$T = 2\pi\sqrt{\frac{I}{M \times B_H}}$$

$$\Rightarrow \quad T \propto \frac{1}{\sqrt{B_H}}$$

So, for two different cases

$$\Rightarrow \quad \frac{T_1}{T_2} = \sqrt{\frac{(B_H)_2}{(B_H)_1}}$$

$$\Rightarrow \quad \frac{2}{T_2} = \sqrt{\frac{18}{24}}$$

$$\therefore \quad T = 2.3\text{ s} \approx 2\text{ s}$$

15 Two bar magnets having same geometry with magnetic moments M and $2M$, are firstly placed in such a way that their similar poles are on the same side, then its period of oscillation is T_1. Now, the

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polarity of one of the magnets is reversed the time period of oscillations becomes T_2. Then,
[CBSE AIPMT 2002]

(a) $T_1 < T_2$ (b) $T_1 > T_2$
(c) $T_1 = T_2$ (d) $T_2 = \infty$

Ans. *(a)*

The time period of bar magnet is

$$T = 2\pi\sqrt{\frac{I}{MH}}$$

where, M= magnetic moment of magnet
I = moment of inertia
and H = horizontal component of magnetic field

When same poles of magnets are placed on same side, then net magnetic moment

$$M_1 = M + 2M = 3M$$

$$\therefore \quad T_1 = 2\pi\sqrt{\frac{I}{M_1 H}}$$

$$= 2\pi\sqrt{\frac{I}{3MH}} \quad ...(i)$$

When opposite poles of magnets are placed on same side, then net magnetic moment

$$M_2 = 2M - M = M$$

$$\therefore \quad T_2 = 2\pi\sqrt{\frac{I}{M_2 H}} = 2\pi\sqrt{\frac{I}{MH}} \quad ...(ii)$$

From Eqs. (i) and (ii), we observe that

$$T_1 < T_2$$

16 Due to the earth's magnetic field, charged cosmic ray particles
[CBSE AIPMT 1997]

(a) can never reach the poles
(b) can never reach the equator
(c) require less kinetic energy to reach the equator than the poles
(d) require greater kinetic energy to reach the equator than the poles

Ans. *(d)*

Earth's magnetic field at poles is vertical (perpendicular to the earth's surface) and horizontal (parallel to the earth's surface) at equator.

Cosmic rays are positively charged particles and its velocity is parallel to the earths magnetic field. So, no magnetic force acts on cosmic ray particles coming at poles, i.e. force

$$(F) = qvB\sin\theta$$

At poles angle between v and B is $\theta = 0°$,
So, $F = 0$
At equator $\theta = 90°$,
So, Force $= qvB\sin 90° = qvB$

This force is maximum and deflects the particles sideways.

Hence, only high energy particles can reach the equator.

17 A bar magnet is oscillating in the earth's magnetic field with a period T. What happens to its period of motion, if its mass is quadrupled?
[CBSE AIPMT 1994]

(a) Motion remains simple harmonic with new period $= \frac{T}{2}$
(b) Motion remains simple harmonic with new period $= 2T$
(c) Motion remains simple harmonic with new period $= 4T$
(d) Motion remains simple harmonic and the period stays nearly constant

Ans. *(b)*

The time period of a bar magnet in a magnetic field is given by

$$T = 2\pi\sqrt{\left(\frac{I}{MB}\right)}$$

where, I is moment of inertia of bar magnet, M is magnetic moment and B is magnetic induction.

When mass is made 4 times, moment of inertia

I becomes 4 times (as $I = mr^2$, $I \propto m$).
From the above equation of time period $T \propto \sqrt{I}$. So, T becomes twice as mass is quadrupled.

TOPIC 3
Magnetic Materials

18 An iron rod of susceptibility 599 is subjected to a magnetising field of 1200 A m^{-1}. The permeability of the material of the rod is
(Take, $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1})
[NEET (Sep.) 2020]

(a) 8.0×10^{-5} T m A^{-1}
(b) $2.4\pi \times 10^{-5}$ T m A^{-1}
(c) $2.4\pi \times 10^{-7}$ T m A^{-1}
(d) $2.4\pi \times 10^{-4}$ T m A^{-1}

Ans. *(d)*

Given, susceptibility, $\chi = 599$
Magnetic field, $B = 1200$ Am^{-1}
Permeability of the material of the rod = ?
As, $\mu_m = \mu_0(1 + \chi)$
$= 4\pi \times 10^{-7}(1 + 599)$
$= 2.4\pi \times 10^{-4}$TmA^{-1}
Hence, correct option is (d).

19 A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence, the rod gains gravitational potential energy. The work required to do this comes from **[NEET 2018]**

(a) the lattice structure of the material of the rod
(b) the magnetic field
(c) the current source
(d) the induced electric field due to the changing magnetic field

Ans. *(c)*

As the source of current is switched on, a magnetic field sets up in between the poles of the electromagnet.

As we know that a diamagnetic substance when placed in a magnetic field acquires a feeble magnetism opposite to the direction of magnetic field.

Also, in the presences of the field (non-uniform), these substances are attracted towards the weaker field, i.e. they move from stronger to weaker magnetic field.

Due to these reasons, the rod is repelled by the field produced to the current source. Hence, it is pushed up, out of horizontal field and gains gravitational potential energy.

20 The magnetic susceptibility is negative for **[NEET 2016]**

(a) paramagnetic material only
(b) ferromagnetic material only
(c) paramagnetic and ferromagnetic materials
(d) diamagnetic material only

Ans. *(d)*

As we know the relation between the magnetic permeability and susceptibility of material, i.e.

$$\mu_r = 1 + \chi_m \quad ...(i)$$

$\because$ For diamagnetic substances, $\mu_r < 1$
So, according to equation (i), the magnetic susceptibility (χ_m) of diamagnetic substance will be negative. While in the case of para and ferromagnetic substances, diamagnetic susceptibility is positive.

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21 There are four light weight rod samples *A, B, C* and *D* separately suspended by thread. A bar magnet is slowly brought near each sample and the following observations are noted

(i) *A* is feebly repelled
(ii) *B* is feebly attracted
(iii) *C* is strongly attracted
(iv) *D* remains unaffected

Which one of the following is true? **[CBSE AIPMT 2011]**

(a) *C* is of a diamagnetic material
(b) *D* is of a ferromagnetic material
(c) *A* is of a non-magnetic material
(d) *B* is of a paramagnetic material

Ans. *(d)*

Paramagnetic material will be feebly attracted, diamagnetic material will be feebly repelled and ferromagnetic material will be strongly attracted.

22 If a diamagnetic substance is brought near the North or the South pole of a bar magnet, it is **[CBSE AIPMT 2009]**

(a) repelled by both the poles
(b) repelled by the North pole and attracted by the South pole
(c) attracted by the North pole and repelled by the South pole
(d) attracted by both the poles

Ans. *(a)*

Diamagnetic substances are weakly magnetised in a direction opposite to that of applied magnetic field. These are repelled in an external magnetic field i.e. have a tendency to move from high to low field region, i.e. it is repelled by both North and South poles of a bar magnet.

23 Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show **[CBSE AIPMT 2007]**

(a) paramagnetism
(b) anti-ferromagnetism
(c) no magnetic property
(d) diamagnetism

Ans. *(a)*

Nickel exhibits ferromagnetism because of a quantum physical effect called exchange coupling in which the electron spins of one atom interact with those of neighbouring atoms. The result is alignment of the magnetic dipole moments of the atoms, in spite of the randomising tendency of atomic collisions. This persistent alignment is what gives ferromagnetic materials their permanent magnetism.

If the temperature of a ferromagnetic material is raised above a certain critical value, called the Curie temperature, the exchange coupling ceases to be effective.

Most such materials become simply paramagnetic, i.e. the dipoles still tend to align with an external field but much more weakly and thermal agitation can now more easily disrupt the alignment.

24 Above Curie temperature **[CBSE AIPMT 2006]**

(a) a ferromagnetic substance becomes paramagnetic
(b) a paramagnetic substance becomes diamagnetic
(c) a diamagnetic substance becomes paramagnetic
(d) a paramagnetic substance becomes ferromagnetic

Ans. *(a)*

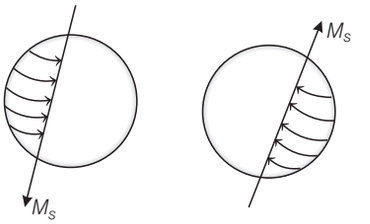
Ferromagnetism decreases with rise in temperature. If we heat a ferromagnetic substance, then at a definite temperature, the ferromagnetic property of the substance suddenly disappears and the substance becomes paramagnetic. The temperature above which a ferromagnetic substance becomes paramagnetic is called the Curie temperature of the substance.

25 If the magnetic dipole moment of an atom of diamagnetic material, paramagnetic material and ferromagnetic material are denoted by μ_d, μ_p and μ_f respectively, then **[CBSE AIPMT 2005]**

(a) $\mu_d \neq 0$ and $\mu_f \neq 0$
(b) $\mu_p = 0$ and $\mu_f \neq 0$
(c) $\mu_d = 0$ and $\mu_p \neq 0$
(d) $\mu_d \neq 0$ and $\mu_p = 0$

Ans. *(c)*

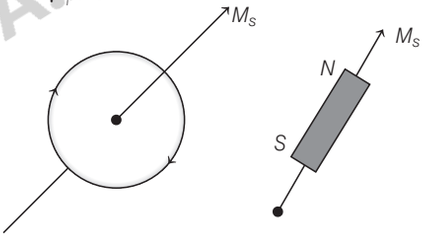
In diamagnetic substances, in each pair of electrons, the spin of both the electrons are in opposite directions. Hence, the electrons of each pair completely cancel the magnetic moment of each other. Thus, the net magnetic moment of each atom of such substances is zero, i.e. $\mu_d = 0$.



The property of paramagnetism is bound in those substances whose atoms or molecules have an excess of electrons spinning in same direction.

Hence, atoms of paramagnetic substances have permanent magnetic moment i.e. $\mu_p \neq 0$.

The property of ferromagnetism is found in substances which acquire very strong magnetism when placed in an external magnetic field. Like the paramagnetic substances each atom of ferromagnetic substances also has a permanent magnetic moment i.e. $\mu_f \neq 0$.



26 According to Curie's law, the magnetic susceptibility of a paramagnetic substance at an absolute temperature T is proportional to **[CBSE AIPMT 2003]**

(a) $\frac{1}{T^2}$ (b) T^2
(c) $\frac{1}{T}$ (d) T

Ans. *(c)*

According to Curie's law, magnetic susceptibility (χ_m) of a paramagnetic substance is inversely proportional to absolute temperature (T) i.e.

$$\chi_m \propto \frac{1}{T}$$

27 A diamagnetic material in a magnetic field moves **[CBSE AIPMT 2003]**

(a) perpendicular to the field
(b) from weaker to the stronger parts of the field

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(c) from stronger to the weaker parts of the field
(d) None of the above

Ans. *(c)*

When a diamagnetic material is placed in an external magnetic field, the spin motion of electrons is so modified that the electrons which produce the magnetic moments in the direction of external field slow down while the electrons which produce magnetic moments in opposite direction get accelerated.

Thus, a net magnetic moment is induced in the opposite direction of applied magnetic field. Hence, the substance is magnetised opposite to the external field. Thus, it moves from stronger to weaker parts of the magnetic field.

Diamagnetism is present in all the substances. However, its effect is so weak in most cases that it gets shifted by other effects like paramagnetism, ferromagmetism etc.

28 In which type of material the magnetic susceptibility does not depend on temperature? **[CBSE AIPMT 2001]**

(a) Diamagnetic (b) Paramagnetic
(c) Ferromagnetic (d) Ferrite

Ans. *(a)*

The magnetic susceptibility of a material is a measure of the ease with which a specimen of that material can be magnetised in a magnetising field. For a diamagnetic substance, magnetic susceptibility (χ_m) is independent of temperature.

29 A diamagnetic substance is brought near a strong magnet, then it is **[CBSE AIPMT 1999]**

(a) attracted by a magnet
(b) repelled by a magnet
(c) repelled by North pole and attracted by South pole
(d) attracted by North pole and repelled by South pole

Ans. *(b)*

When diamagnetic substances are placed in magnetic field of a strong magnet, then it is feebly magnetised in the opposite direction of field or it is repelled by strong magnet.

30 For protecting a sensitive equipment from the external magnetic field, it should be **[CBSE AIPMT 1998]**

(a) placed inside an aluminium can
(b) placed inside an iron can
(c) wrapped with insulation around it when passing current through it
(d) surrounded with fine copper sheet

Ans. *(b)*

Iron is a ferromagnetic substance. There are no magnetic lines of force inside a ferromagnetic substance. So, equipment may be protected by placing it inside the can made of a ferromagnetic substance. Hence, it is placed inside an iron can.

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20

Electromagnetic Induction

TOPIC 1
Magnetic Flux, Faraday's and Lenz's Laws

01 The magnetic flux linked with a coil (in Wb) is given by the equation $\phi = 5t^2 + 3t + 16$
The magnitude of induced emf in the coil at the fourth second will be **[NEET (Oct.) 2020]**

(a) 33 V (b) 43 V
(c) 108 V (d) 10 V

Ans. *(d)*

Magnetic flux linked with coil,
$$\phi = (5t^2 + 3t + 16)\,\text{Wb}$$
Magnitude of induced emf,
$$e = \frac{d\phi}{dt} = \frac{d}{dt}(5t^2 + 3t + 16) = 10t + 3$$
At $t = 3$ s,
$$e_3 = 10 \times 3 + 3 = 33\,\text{V}$$
At $t = 4$ s
$$e_4 = 10 \times 4 + 3 = 43\,\text{V}$$
$\therefore$ Induced emf in coil at the fourth second is given as
$$e = e_4 - e_3 = 43 - 33 = 10\,\text{V}$$

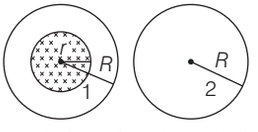
02 A coil of 800 turns effective area 0.05 m^2 is kept perpendicular to a magnetic field 5×10^{-5} T. When the plane of the coil is rotated by 90º around any of its co-planar axis in 0.1 s, the emf induced in the coil will be **[NEET (National) 2019]**

(a) 0.2 V (b) 2×10^{-3} V
(c) 0.02 V (d) 2 V

Ans. *(c)*

Given, area of coil, $A = 0.05\,\text{m}^2$
magnetic field, $B = 5 \times 10^{-5}$ T and number of turns, $N = 800$.
The magnetic flux linked with the coil is
$$\phi = N(\mathbf{B} \cdot \mathbf{A}) = N\,BA\cos\theta \quad \ldots(\text{i})$$
where, θ is the angle between **B** and **A**.
The emf induced when coil is rotated from $\theta_1 = 0°$ to $\theta_2 = 90°$ is
$$e = -\frac{\Delta\phi}{\Delta t} = -\frac{\Delta}{\Delta t}(NBA\cos\theta) \text{ [using Eq. (i)]}$$
$$= -\frac{NBA}{\Delta t}(\cos\theta_2 - \cos\theta_1) \quad \ldots(\text{ii})$$
Here, $\Delta t = 0.1$ s
Thus, substituting the given values in Eq. (ii), we get
$$e = -\frac{800 \times 5 \times 10^{-5} \times 0.05 \times [\cos 90° - \cos 0°]}{0.1}$$
$$= 2000 \times 10^{-5} = 0.02\,\text{V}$$

03 A uniform magnetic field is restricted within a region of radius *r*. The magnetic field changes with time at a rate $\frac{d\mathbf{B}}{dt}$. Loop 1 of radius $R > r$ encloses the region *r* and loop 2 of radius *R* is outside the region of magnetic field as shown in the figure. Then, the emf generated is **[NEET 2016]**

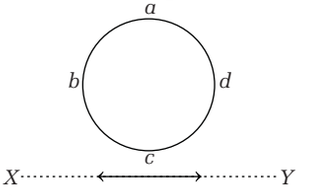


(a) zero in loop 1 and zero in loop 2
(b) $-\frac{dB}{dt}\pi r^2$ in loop 1 and $-\frac{dB}{dt}\pi r^2$ in loop 2
(c) $-\frac{dB}{dt}\pi R^2$ in loop 1 and zero in loop 2
(d) $-\frac{dB}{dt}\pi r^2$ in loop 1 and zero in loop 2

Ans. *(c)*

Induced emf in the region is given by
$$|e| = \frac{d\phi}{dt}$$
where, $\phi = BA = \pi r^2 B$
$$\Rightarrow \quad \frac{d\phi}{dt} = -\pi r^2 \frac{dB}{dt}$$
Rate of change of magnetic flux associated with loop 1
$$e_1 = -\frac{d\phi_1}{dt} = -\pi r^2 \frac{dB}{dt}$$
Similarly e_2 = emf associated with loop 2
$$= -\frac{d\phi_2}{dt} = 0 \qquad [\because \phi_2 = 0]$$

04 An electron moves on a straight line path *XY* as shown. The *abcd* is a coil adjacent in the path of electron. What will be the direction of current, if any induced in the coil? **[CBSE AIPMT 2015]**



(a) *abcd*
(b) *adcb*
(c) The current will reverse its direction as the electron goes past the coil
(d) No current induced

Ans. *(d)*

First current develops in direction of *abcd* but when electron moves away then magnetic field inside loop decreases and current changes its direction.

05 A coil of resistance 400 Ω is placed in a magnetic field. If the

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magnetic flux ϕ (Wb) linked with the coil varies with time t (second) as $\phi = 50t^2 + 4$. The current in the coil at $t = 2$ s is **[CBSE AIPMT 2012]**

(a) 0.5 A (b) 0.1 A (c) 2 A (d) 1 A

Ans. *(a)*

Induced emf in a coil is given by

$$E = \left| -\frac{d\phi}{dt} \right|$$

Given, $\phi = 50t^2 + 4$

and resistance, $R = 400\,\Omega$

So, $E = \left| -\frac{d\phi}{dt} \right|_{t=2} = |100t|_{t=2} = 200$ V

So, current in the coil will be

$$I = \frac{E}{R} = \frac{200}{400} = \frac{1}{2} = 0.5\text{ A}$$

06 A conducting circular loop is placed in a uniform magnetic field, $B = 0.025$ T with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mm s^{-1}. The induced emf when the radius is 2 cm, is **[CBSE AIPMT 2010]**

(a) $2\pi\mu$V (b) $\pi\mu$V (c) $\frac{\pi}{2}\mu$V (d) $2\,\mu$V

Ans. *(b)*

Magnetic flux ϕ linked with magnetic field **B** and area **A** is given by

$$\phi = \mathbf{B}\cdot\mathbf{A} = |\mathbf{B}||\mathbf{A}|\cos\theta$$

Here, $\theta = 0°$

So, $\phi = BA = B\pi r^2$

Now, Induced emf, $|e| = \left|\frac{-d\phi}{dt}\right| = B\pi(2r)\frac{dr}{dt}$

$= 0.025 \times \pi \times 2 \times 2 \times 10^{-2} \times 1 \times 10^{-3} = \pi\mu$V

07 A rectangular, a square, a circular and an elliptical loop, all in the xy-plane, are moving out of a uniform magnetic field with a constant velocity, $\mathbf{v} = v\hat{\mathbf{i}}$. The magnetic field is directed along the negative z-axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for **[CBSE AIPMT 2009]**

(a) the rectangular, circular and elliptical loops

(b) the circular and the elliptical loops

(c) only the elliptical loop

(d) any of the four loops

Ans. *(b)*

Area coming out per second from the magnetic field is not constant for elliptical and circular loops, so induced emf, during the passage out of these loops, from the field region will not remain constant.

08 A conducting circular loop is placed in a uniform magnetic field 0.04 T with its plane perpendicular to the magnetic field. The radius of the loop starts shrinking at $2\,\mathbf{mm\ s^{-1}}$. The induced emf in the loop when the radius is 2 cm is **[CBSE AIPMT 2009]**

(a) $3.2\,\pi\,\mu$V (b) $4.8\,\pi\,\mu$V

(c) $0.8\,\pi\,\mu$V (d) $1.6\,\pi\,\mu$V

Ans. *(a)*

Magnetic field, $B = 0.04$ T and rate of change of radius of coil due to shrinkage,

$\frac{-dr}{dt} = 2\text{ mm s}^{-1}$

Induced emf,

$$e = \frac{-d\phi}{dt} = -B\frac{dA}{dt} = -B\frac{d(\pi r^2)}{dt}$$

$$= -B\pi 2r\frac{dr}{dt}$$

Now, if $r = 2$ cm

$e = -0.04 \times \pi \times 2 \times 2 \times 10^{-2} \times 2 \times 10^{-3}$

$= 3.2\,\pi\mu$V

09 A circular disc of radius 0.2 m is placed in a uniform magnetic field of induction $\frac{1}{\pi}$ (Wb/m^2) in such a way that its axis makes an angle of 60° with **B.** The magnetic flux linked with the disc is **[CBSE AIPMT 2008]**

(a) 0.02 Wb (b) 0.06 Wb

(c) 0.08 Wb (d) 0.01 Wb

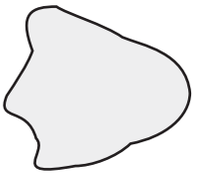
Ans. *(a)*

Magnetic flux $\phi = \mathbf{B}\cdot\mathbf{A}$

$\phi = BA\cos\theta$

$= \frac{1}{\pi} \times \pi(0.2)^2 \cos 60° = 0.02$ Wb

10 As a result of change in the magnetic flux linked to the closed loop shown in the figure, an emf V volt is induced in the loop. The work done (joule) in taking a charge q coulomb once along the loop is **[CBSE AIPMT 2005]**



(a) qV (b) zero

(c) $2\,qV$ (d) $\frac{qV}{2}$

Ans. *(a)*

Work done in moving a charge through potential difference V is given by $W = qV$

11 The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. Then the total quantity of electric charge q that passes any point in the circuit during the time Δt is represented by **[CBSE AIPMT 2004]**

(a) $q = \frac{1}{R}\cdot\frac{\Delta\phi}{\Delta t}$ (b) $q = \frac{\Delta\phi}{R}$

(c) $q = \frac{\Delta\phi}{\Delta t}$ (d) $q = R\cdot\frac{\Delta\phi}{\Delta t}$

Ans. *(b)*

From Faraday's second law, emf induced in the circuit

$$e = \frac{\Delta\phi}{\Delta t}$$

If R is the resistance of the circuit, then

$$i = \frac{e}{R} = \frac{\Delta\phi}{R\Delta t}$$

Thus, charge passing through the circuit,

$$q = i \times \Delta t$$

$$\Rightarrow \quad q = \frac{\Delta\phi}{R\Delta t}\cdot\Delta t \ \Rightarrow\ q = \frac{\Delta\phi}{R}$$

12 The total charge induced in a conducting loop when it is moved in magnetic field depends on **[CBSE AIPMT 1992]**

(a) the rate of change of magnetic flux

(b) initial magnetic flux

(c) the total change in magnetic flux

(d) final magnetic flux

Ans. *(c)*

Total charge induced in a conducting loop is

$$q = \int i\,dt$$

As, $i = \frac{e}{R}$

$$\therefore \quad q = \int \frac{e}{R}\,dt = \frac{1}{R}\int e\,dt$$

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Induced emf e is given by

$$e = -\frac{d\phi}{dt}$$

$$\therefore \quad q = \frac{1}{R}\int\left(-\frac{d\phi}{dt}\right)dt = \frac{1}{R}\int d\phi$$

Hence, total charge induced in the conducting loop depends upon resistance of loop and change in magnetic flux.

13 A rectangular coil of 20 turns and area of cross-section 25 sq cm has a resistance of 100 Ω. If a magnetic field which is perpendicular to the plane of coil changes at a rate of 1000 T/s, the current in the coil is

[CBSE AIPMT 1992]

(a) 1 A (b) 50 A
(c) 0.5 A (d) 5 A

Ans. *(c)*

Total number of turns, $N = 20$

Area of coil, $A = 25\,cm^2$

$$= 25 \times 10^{-4}\ m^2$$

Change in magnetic field w.r.t. t

$$\frac{dB}{dt} = 1000\ T/s$$

Resistance of coil $R = 100\ \Omega$

$i = ?$

$$\text{Induced current, } i = \frac{e}{R} = \frac{NA\frac{dB}{dt}}{R} \qquad \left[e = NA\frac{dB}{dt}\right]$$

$$= \frac{20 \times 25 \times 10^{-4} \times 1000}{100}$$

$$= 0.5\ A$$

14 A magnetic field of 2×10^{-2} T acts at right angles to a coil of area 100 cm^2, with 50 turns. The average emf induced in the coil is 0.1 V, when it is removed from the field in t second. The value of t is

[CBSE AIPMT 1991]

(a) 10 s (b) 0.1 s (c) 0.01 s (d) 1 s

Ans. *(b)*

Emf induced in the coil due to change in magnetic flux

$$e = -\frac{d\phi}{dt} = -\frac{(\phi_2 - \phi_1)}{dt}$$

When magnetic field is perpendicular to coil

$$\phi_1 = NBA$$

When coil is removed, $\phi_2 = 0$

$$\text{So,} \quad e = -\frac{(0 - NBA)}{dt} \quad \text{or} \quad dt = \frac{NBA}{e}$$

Here, $N = 50$, $B = 2 \times 10^{-2}$ T, $A = 100\ cm^2$

$$= 10^{-2}\ m^2 \text{ and } e = 0.1\ V$$

$$\therefore \quad dt = \frac{50 \times 2 \times 10^{-2} \times 10^{-2}}{0.1} = 0.1\ s$$

15 In a region of uniform magnetic induction $B = 10^{-2}$ T, a circular coil of radius 30 cm and resistance π^2 ohm is rotated about an axis which is perpendicular to the direction of B and which forms a diameter of the coil.
If the coil rotates at 200 rpm the amplitude of the alternating current induced in the coil is

[CBSE AIPMT 1988]

(a) $4\pi^2$ mA (b) 30 mA
(c) 6 mA (d) 200 mA

Ans. *(c)*

When a coil of N number of turns and area A is rotated in external magnetic field **B**, magnetic flux linked with the coil changes and hence an emf is induced in the coil. At this instant t, if e is the emf induced in the coil, then

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(NBA\cos\omega t)$$

Magnetic flux $\phi = NBA\cos\omega t$

$$\therefore \quad e = -NBA\frac{d}{dt}(\cos\omega t)$$

$$= NBA\,\omega\sin\omega t$$

The induced emf will be maximum, when

$$\sin\omega t = \text{maximum} = 1$$

$$\therefore \quad e_{max} = e_0 = NBA\omega$$

So, alternating emf induced is

$$e = e_0\sin\omega t$$

$$\text{Maximum current } i_0 = \frac{e_0}{R} = \frac{NBA\omega}{R}$$

Given, $N = 1$, $B = 10^{-2}$ T

$$A = \pi(0.3)^2\ m^2,\ R = \pi^2\ \Omega$$

$$f = \frac{200}{60}s^{-1} \quad \text{and} \quad \omega = 2\pi\left(\frac{200}{60}\right)$$

$$\therefore \quad i_0 = \frac{1 \times 10^{-2} \times \pi(0.3)^2 \times 2\pi \times 200}{60 \times \pi^2}$$

TOPIC 2
Motional EMF and Eddy Current

16 A wheel with 20 metallic spokes each 1 m long is rotated with a speed of 120 rpm in a plane perpendicular to a magnetic field of 0.4 G. The induced emf between the axle and rim of the wheel will be (1 G = 10^{-4} T)

[NEET (Oct.) 2020]

(a) 2.51×10^{-4} V (b) 2.51×10^{-5} V
(c) 4.0×10^{-5} V (d) 2.51 V

Ans. *(a)*

Given, magnetic field,

$$B = 0.4\,G = 0.4 \times 10^{-4}\,T$$

$$l = 1\,m$$

$$\text{Frequency, } f = 12\,rpm = \frac{120}{60}\,rps = 2\,Hz$$

Induced emf between the axle and rim of the wheel is given as

$$e = \frac{1}{2}B\omega l^2 = \frac{1}{2}B(2\pi f)l^2 = \pi Bfl^2$$

$$= 3.14 \times 0.4 \times 10^{-4} \times 2 \times 1^2$$

$$= 2.51 \times 10^{-4}\,V$$

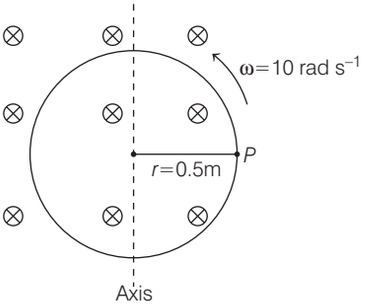
17 A cycle wheel of radius 0.5 m is rotated with constant angular velocity of 10 rad/s in a region of magnetic field of 0.1 T which is perpendicular to the plane of the wheel. The EMF generated between its centre and the rim is

[NEET (Odisha) 2019]

(a) 0.25 V (b) 0.125 V
(c) 0.5 V (d) zero

Ans. *(b)*

When a conducting disc or wheel of radius r rotates with constant angular velocity of ω about its axis in a uniform magnetic field perpendicular to its plane and parallel to its axis of rotation, then,



Induced emf is given by, $e = \frac{1}{2}B\omega r^2$ ...(i)

Here, $B = 0.1$ T, $\omega = 10$ rad/s, $r = 0.5$ m

Substituting these values in Eq. (i), we get

$$\therefore \quad e = \frac{1}{2} \times 0.1 \times 10 \times (0.5)^2 = \frac{1}{8}\,V$$

$$= 0.125\,V$$

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18 In which of the following devices, the eddy current effect is not used? **[NEET (National) 2019]**

(a) Magnetic braking in train
(b) Electromagnet
(c) Electric heater
(d) Induction furnace

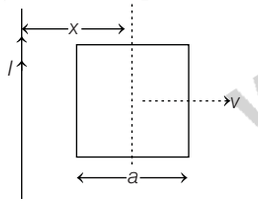
Ans. *(c)*

Electric heaters are not based on the eddy current effect. Rather their working is based on Joule's heating effect of current. According to this effect, the passage of an electric current through a resistor produces heat.

However, when a changing magnetic flux is applied to a bulk piece of conducting material, then circulating current is induced in the body of this conductor, which is usually known as eddy currents. This current shows both heating and magnetic effects.

Thus, it is the basic principle behind the working of magnetic braking in train, electromagnet and induction furnace.

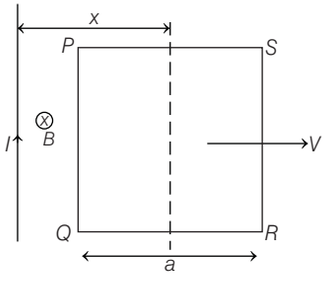
19 A conducting square frame of side '*a*' and a long straight wire carrying current *I* are located in the same plane as shown in the figure. The frame moves to the right with a constant velocity '*v*'. The emf induced in the frame will be proportional to **[CBSE AIPMT 2015]**



(a) $\frac{1}{x^2}$ (b) $\frac{1}{(2x-a)^2}$

(c) $\frac{1}{(2x+a)^2}$ (d) $\frac{1}{(2x-a)(2x+a)}$

Ans. *(d)*



Potential difference across *PQ* is

$$V_P - V_Q = B_1(a)v = \frac{\mu_0 I}{2\pi\left(x-\frac{a}{2}\right)}av$$

Potential difference across side *RS* of frame is

$$V_S - V_R = B_2(a)v = \frac{\mu_0 I}{2\pi\left(x+\frac{a}{2}\right)}av$$

Hence, the net potential difference in the loop will be

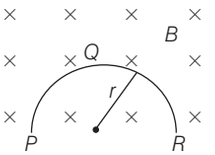
$$V_{net} = (V_P - V_Q) - (V_S - V_R)$$

$$= \frac{\mu_0 iav}{2\pi}\left[\frac{1}{\left(x-\frac{a}{2}\right)} - \frac{1}{\left(x+\frac{a}{2}\right)}\right]$$

$$= \frac{\mu_0 iav}{2\pi}\left(\frac{a}{\left(x-\frac{a}{2}\right)\left(x+\frac{a}{2}\right)}\right)$$

Thus, $V_{net} \propto \frac{1}{(2x-a)(2x+a)}$

20 A thin semicircular conducting ring (*PQR*) of radius *r* is falling with its plane vertical in a horizontal magnetic field *B*, as shown in figure. The potential difference developed across the ring when its speed is *v*, is **[CBSE AIPMT 2014]**



(a) zero
(b) $Bv\pi r^2/2$ and P is at higher potential
(c) πrBv and R is at higher potential
(d) $2rBv$ and R is at higher potential

Ans. *(d)*

Concept An induced emf (BLv) called motional emf is produced by moving a conductor instead of varying the magnetic field.

For emf, $e = Bv(L_{eff}) = Bv \times (2r) = 2Bvr$
$[\because L_{eff} = \text{diameter} = 2r]$

R will be at higher potential, we can find it by using right hand rule. The electrons of wire will move towards end *P* due to electric force and at end *R* the excess positive change will be left.

21 A wire loop is rotated in a magnetic field. The frequency of change of direction of the induced emf is **[NEET 2013]**

(a) once per revolution
(b) twice per revolution
(c) four times per revolution
(d) six times per revolution

Ans. *(b)*

If a wire loop is rotated in a magnetic field, the frequency of change in the direction of the induced emf is twice per revolution.

22 A conductor of length 0.4 m is moving with a speed of 7 m/s perpendicular to a magnetic field of intensity 0.9 Wb/m^2. The induced emf across the conductor is **[CBSE AIPMT 1995]**

(a) 1.26 V (b) 2.52 V
(c) 5.04 V (d) 25.2 V

Ans. *(b)*

Given, length of conductor (l) = 0.4 m
speed (v) = 7 m/s
Magnetic field (B) = 0.9 Wb/m^2
Induced emf, $e = Blv \sin\theta$ [$\theta = 90°$ as $\mathbf{B} \perp \mathbf{v}$]
$= 0.9 \times 0.4 \times 7 \times \sin 90° = 2.52$ V

23 Eddy currents are produced when **[CBSE AIPMT 1988]**

(a) a metal is kept in varying magnetic field
(b) a metal is kept in steady magnetic field
(c) a circular coil is placed in a magnetic field
(d) current is passed through a circular coil

Ans. *(a)*

Eddy currents are the currents induced in the body of a conductor when the amount of magnetic flux linked with the conductor changes.

e.g. when we move a metal plate out of a magnetic field, the relative motion of the field and the conductor again induces a current in the conductor for which conduction electrons move in closed loops forming circular eddy currents in such a way that it opposes the magnetic field that created it as if the electrons are caught in an eddy or whirlpool. It is also called Foucault current.

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TOPIC 3
Self and Mutual Inductances

24 Two conducting circular loops of radii R_1 and R_2 are placed in the same plane with their centres coinciding. If $R_1 >> R_2$, the mutual inductance M between them will be directly proportional to **[NEET 2021]**

(a) $\frac{R_1}{R_2}$ (b) $\frac{R_2}{R_1}$ (c) $\frac{R_1^2}{R_2}$ (d) $\frac{R_2^2}{R_1}$

Ans. *(d)*

Since, both conducting circular loops are in same plane and their centres are coinciding.

Hence, magnetic flux, $\phi = Mi$ ...(i)

Here, M is the mutual inductance.

Also, the magnetic flux, $\phi = BA$

Here, B is the magnetic field and $A (= \pi R_2^2)$ is the area of the inner circular loop.

If the current passing through the outer loop is i, then the magnetic field,

$$B = \frac{\mu_0 i}{2R_1}$$

Magnetic flux, $\phi = BA$

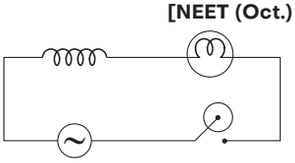
$$\Rightarrow \quad \phi = \frac{\mu_0 i}{2R_1}\pi R_2^2 \qquad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$$M = \frac{\mu_0}{2R_1}\pi R_2^2$$

Thus, the mutual inductance is directly proportional to the $\frac{R_2^2}{R_1}$.

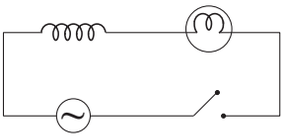
25 A light bulb and an inductor coil are connected to AC ac source through a key as shown in the figure below. The key is closed and after sometime an iron rod is inserted into the interior of the inductor. The glow of the light bulb **[NEET (Oct.) 2020]**



(a) decreases
(b) remains unchanged
(c) will fluctuate
(d) increases

Ans. *(a)*

When an iron rod is inserted into the interior of the inductor, then inductance (L) of the coil increases.



Hence, inductive reactance ($X_L = \omega L$) also increases.

∴ Current in the circuit is given as

$$I = \frac{e}{X_L}$$

Hence, when X_L increases, then current I decreases. Therefore, glow of the light bulb will decrease.

26 The magnetic potential energy stored in a certain inductor is 25 mJ, when the current in the inductor is 60 mA.

This inductor is of inductance **[NEET 2018]**

(a) 1.389 H
(b) 138.88 H
(c) 0.138 H
(d) 13.89 H

Ans. *(d)*

Given, magnetic potential energy stored in an inductor,

$U = 25\,\text{mJ} = 25 \times 10^{-3}\,\text{J}$

Current in an inductor, $I_0 = 60\,\text{mA}$
$= 60 \times 10^{-3}\,\text{A}$

As, the expression for energy stored in an inductor is given as

$$U = \frac{1}{2}LI_0^2$$

where, L is the inductance of the inductor.

Substituting the given values in above equation., we get

$$(25 \times 10^{-3}) = \frac{1}{2} \times L \times (60 \times 10^{-3})^2$$

$$\Rightarrow \quad L = \frac{2 \times 25 \times 10^{-3}}{3600 \times 10^{-6}} = \frac{500}{36}$$

or $L = 13.89\,\text{H}$

27 A long solenoid of diameter 0.1 m has 2×10^4 turns per metre. At the centre of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduces at a constant rate to 0 A from 4 A in 0.05 s. If the resistance of the coil is $10\pi^2\ \Omega$, the total charge flowing through the coil during this time is **[NEET 2017]**

(a) $32\pi\,\mu\text{C}$ (b) $16\,\mu\text{C}$
(c) $32\,\mu\text{C}$ (d) $16\pi\,\mu\text{C}$

Ans. *(c)*

Thinking Process Current induced in the coil is given by

$$i = \frac{1}{R}\left(\frac{d\phi}{dt}\right)$$

$$\Rightarrow \quad \frac{\Delta q}{\Delta t} = \frac{1}{R}\left(\frac{\Delta\phi}{\Delta t}\right)$$

Given, resistance of the solenoid,

$$R = 10\pi^2\ \Omega$$

Radius of second and coil $r = 10^{-2}$

$$\Delta t = 0.05\ \text{s},\ \Delta i = 4 - 0 = 4\ \text{A}$$

Charge flowing through the coil is given by

$$\Delta q = \left(\frac{\Delta\phi}{\Delta t}\right)\frac{1}{R}(\Delta t)$$

$$= \mu_0 N_1 N_2 \pi r^2 \left(\frac{\Delta i}{\Delta t}\right)\frac{1}{R}\Delta t$$

$$= 4\pi \times 10^{-7} \times 2 \times 10^4 \times 100 \times \pi \times (10^{-2})^2 \times \left(\frac{4}{0.05}\right) \times \frac{1}{10\pi^2} \times 0.05$$

$$= 32 \times 10^{-6}\ \text{C} = 32\,\mu\text{C}$$

28 A long solenoid has 1000 turns. When a current of 4A flows through it, the magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self-inductance of the solenoid is **[NEET 2016]**

(a) 3 H (b) 2 H
(c) 1 H (d) 4 H

Ans. *(c)*

Given, Number of turns of solenoid, $N = 1000$.

Current, $I = 4A$

Magnetic flux, $\phi_B = 4 \times 10^{-3}$ Wb

∵ Self inductance of solenoid is given by

$$L = \frac{\phi_B . N}{I} \qquad ...(i)$$

Substitute the given values in Eq. (i), we get

$$L = \frac{4 \times 10^{-3} \times 1000}{4} = 1H$$

29 The current (I) in the inductance is varying with time according to the plot shown in figure. **[CBSE AIPMT 2012]**

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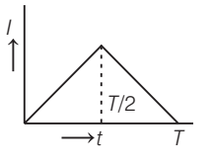
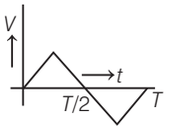
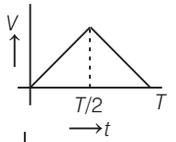
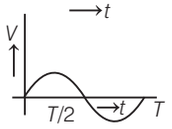
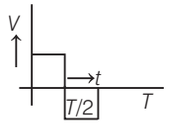


Which one of the following is the correct variation of voltage with time in the coil?

(a) 

(b) 

(c) 

(d) 

Ans. *(d)*

For inductor, as we know induced voltage

for $t = 0$ to $t = T/2$,

$$V = L\frac{dI}{dt} = L\frac{d}{dt}\left(\frac{2I_0 t}{T}\right) = \text{constant}$$

For $t = T/2$ to $t = T$,

$$V = L\frac{dI}{dt} = \left(\frac{-2I_0 t}{T}\right) = -\text{constant}$$

So, answer can be represented with graph (d).

30 A long solenoid has 500 turns. When a current of 2 A is passed through it, the resulting magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self-inductance of the solenoid is **[CBSE AIPMT 2008]**

(a) 2.5 H (b) 2 H
(c) 1 H (d) 4 H

Ans. *(c)*

Net flux through solenoid is,

$$\phi_{net} = N\phi$$

$$\therefore \quad \phi_{net} = 500 \times 4 \times 10^{-3} = 2 \text{ Wb}$$

where, ϕ = flux through each turn, and N = total number of turns

Also, $\phi_{net} = Li = 2$ Wb

Now, $L \times 2 = 2$

$\Rightarrow$ Self-inductance, $L = 1$H

31 Two coils of self-inductances 2 mH and 8 mH are placed so close together that the effective flux in one coil is completely linked with the other. The mutual inductance between these coils is **[CBSE AIPMT 2006]**

(a) 10 mH (b) 6 mH
(c) 4 mH (d) 16 mH

Ans. *(c)*

When the total flux associated with one coil links with the other i.e. a case of maximum flux linkage, then mutual induction in coil 1 due coil 2 is

$$M_{12} = \frac{N_2 \phi_{B_2}}{i_1}$$

and mutual induction in coil 2 due to coil 1 is

$$M_{21} = \frac{N_1 \phi_{B_1}}{i_2}$$

Similarly, self-inductance in coil 1 is

$$L_1 = \frac{N_1 \phi_{B_1}}{i_1}$$

and self-inductance in coil 2 is

$$L_2 = \frac{N_2 \phi_{B_2}}{i_2}$$

If all the flux of coil 2 links coil 1 and *vice-versa*, then

$$\phi_{B_2} = \phi_{B_1}$$

Since, $M_{12} = M_{21} = M$, hence we have

$$M_{12} M_{21} = M^2$$

$$= \frac{N_1 N_2 \phi_{B_1} \phi_{B_2}}{i_1 i_2} = L_1 L_2$$

$\therefore M_{max} = \sqrt{L_1 L_2}$

Given, $L_1 = 2$ mH, $L_2 = 8$ mH

$\therefore \quad M_{max} = \sqrt{2 \times 8} = \sqrt{16} = 4$ mH

32 In an inductor of self-inductance L = 2 mH, current changes with time according to relation $i = t^2 e^{-t}$. At what time emf is zero? **[CBSE AIPMT 2001]**

(a) 4 s (b) 3 s
(c) 2 s (d) 1 s

Ans. *(c)*

It is given that emf is zero i.e.,

$$e = -L\frac{di}{dt} = 0$$

or $$L\frac{di}{dt} = 0$$

or $$\frac{d}{dt}(t^2 e^{-t}) = 0 \quad (\text{As}, i = t^2 e^{-t})$$

or $$2t \times e^{-t} + t^2 \times (-1) e^{-t} = 0$$

or $te^{-t}(2 - t) = 0$ or $t = 2$s $\quad (\because te^{-t} \neq 0)$

33 Two coils have a mutual inductance of 0.005 H. The current changes in the first coil according to equation $i = i_0 \sin\omega t$, $i_0 = 10$ A and $\omega = 100\pi$ rad/s. The maximum value of emf in the second coil is **[CBSE AIPMT 1998]**

(a) 2π (b) 5π
(c) π (d) 4π

Ans. *(b)*

Problem Solving Strategy Differentiate the given equation of current changing in first coil and find out the maximum change in $\frac{di}{dt}$.

The given equation of current changing in the first coil is

$$i = i_0 \sin\omega t \quad \ldots(i)$$

Differentiating Eq. (i) w.r.t. t, we have

$$\frac{di}{dt} = \frac{d}{dt}(i_0 \sin\omega t)$$

or $$\frac{di}{dt} = i_0 \frac{d}{dt}(\sin\omega t)$$

or $$\frac{di}{dt} = i_0 \omega \cos\omega t$$

For maximum $\frac{di}{dt}$, the value of $\cos\omega t$ should be equal to 1.

So, $$\left(\frac{di}{dt}\right)_{max} = i_0 \omega$$

The maximum value of emf is given by

$$\therefore \quad e_{max} = M\left(\frac{di}{dt}\right)_{max} = Mi_0\omega$$

As, $M = 0.005$ H, $i_0 = 10$ A, $\omega = 100\pi$ rad/s

$$\therefore \quad e_{max} = 0.005 \times 10 \times 100\pi = 5\pi$$

34 A varying current in a coil changes from 10 A to zero in 0.5 s. If the average emf induced in the coil is 220 V, the self-inductance of the coil is **[CBSE AIPMT 1995]**

(a) 5 H (b) 6 H (c) 11 H (d) 12 H

Ans. *(c)*

Emf induced in the coil of self-inductance (L) is given by

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(Li) \quad \text{or} \quad e = -L\frac{di}{dt}$$

$\left(\frac{di}{dt} = \text{rate of flow of current in coil}\right)$

As, $di = i_2 - i_1 = 0 - 10 = -10$ A

$dt = 0.5$ s

$e = 220$ V

$$\therefore \quad 220 = -L\frac{(-10)}{0.5}$$

or $$L = \frac{220}{20} = 11\text{H}$$

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35 If N is the number of turns in a coil, the value of self-inductance varies as **[CBSE AIPMT 1993]**

(a) N^0 (b) N (c) N^2 (d) N^{-2}

Ans. *(c)*

Magnetic flux, $\phi = BA$

and magnetic field due to circular coil is

$$B = \frac{\mu_0 Ni}{2R}$$

As self-inductance,

$$L = \frac{N\phi}{i}$$

$$\therefore \quad L = \frac{N}{i}(BA) = \frac{N}{i}\left(\frac{\mu_0 Ni}{2R}\right)A$$

$$= \frac{\mu_0 N^2 A}{2R}$$

$$\therefore \quad L \propto N^2$$

36 What is the self-inductance of a coil which produces 5 V when the current changes from 3 A to 2 A in one millisecond? **[CBSE AIPMT 1993]**

(a) 5000 H (b) 5 mH
(c) 50 H (d) 5 H

Ans. *(b)*

Emf induced in the coil is given by

$$e = -\frac{d\phi}{dt}$$

If coil has self-inductance (L) and current i, then induced emf is given by

$$e = -\frac{d}{dt}(Li) \quad \text{or} \quad e = -L\frac{di}{dt}$$

$$\therefore \quad L = \frac{|e|}{\frac{di}{dt}}$$

Given, $|e| = 5\,\text{V}, di = 3 - 2 = 1\,\text{A}$

$dt = 1\,\text{ms} = 1 \times 10^{-3}\,\text{s}$

$$\therefore \quad L = \frac{5 \times 10^{-3}}{1} = 5\,\text{mH}$$

37 A 100 mH coil carries a current of 1 A. Energy stored in its magnetic field is **[CBSE AIPMT 1991]**

(a) 0.5 J (b) 1 A
(c) 0.05 J (d) 0.1 J

Ans. *(c)*

Energy stored in coil is

$$E = \frac{1}{2}Li^2$$

where, L is self-inductance of coil and i is current induced. Here, L = 100 mH $= 100 \times 10^{-3}$ H and i = 1A

$$\therefore \; E = \frac{1}{2} \times (100 \times 10^{-3}) \times (1)^2 = 0.05\,\text{J}$$

38 If the number of turns per unit length of a coil of solenoid is doubled, the self-inductance of the solenoid will **[CBSE AIPMT 1991]**

(a) remain unchanged
(b) be halved
(c) be doubled
(d) become four times

Ans. *(d)*

A long solenoid is that whose length is very large as compared to its radius of cross-section. If N is total number of turns in the solenoid, A is area of each turn of the solenoid and l is length of solenoid, then self-inductance of solenoid is given by

$$L = \frac{\mu_0 N^2 A}{l} \Rightarrow L = \mu_0 n^2 Al$$

(n = number of turns per unit length)

So, $L \propto n^2$

When n^2 is doubled, L becomes 4 times.

39 The current in self-inductance $L = 40\,\text{mH}$ is to be increased uniformly from 1 A to 11 A in 4 millisecond. The emf induced in inductor during the process is **[CBSE AIPMT 1990]**

(a) 100 V (b) 0.4 V
(c) 4 V (d) 440 V

Ans. *(b)*

Emf induced in the coil due to change in magnetic flux

$$e = -\frac{d\phi}{dt} = -\frac{(\phi_2 - \phi_1)}{dt}$$

When magnetic field is perpendicular to coil

$$\phi_1 = NBA$$

When coil is removed, $\phi_2 = 0$

So, $\quad e = -\dfrac{(0 - NBA)}{dt} \quad \text{or} \quad dt = \dfrac{NBA}{e}$

Here, $N = 50$, $B = 2 \times 10^{-2}$ T, $A = 100\,\text{cm}^2$ $= 10^{-2}\,\text{m}^2$ and $e = 0.1\,\text{V}$

$$\therefore \quad dt = \frac{50 \times 2 \times 10^{-2} \times 10^{-2}}{0.1} = 0.1\,\text{s}$$

40 An inductor may store energy in **[CBSE AIPMT 1990]**

(a) its electric field
(b) its coils
(c) its magnetic field
(d) Both in electric and magnetic fields

Ans. *(c)*

When the magnetic flux linked with a coil changes, an induced emf acts in the coil which is given by

$$e = -\frac{d\phi}{dt}$$

The magnetic flux linked with a coil carrying a current i, is proportional to i.

or $\quad \phi \propto i \quad \text{or} \quad \phi = Li$

$$\therefore \quad e = -\frac{d\phi}{dt} = -L\frac{di}{dt}$$

The work done in maintaining the current for time dt

$$= -e\,i\,dt = L\frac{di}{dt}\,i\,dt$$

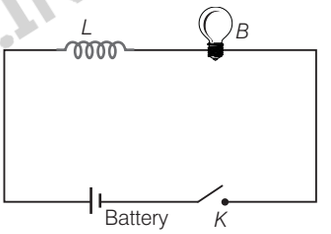
and the total work done while the current i_0 is being established

$$W = \int_0^t L\frac{di}{dt}\,i\,dt = \int_0^{i_0} L\,i\,di$$

$$= \frac{1}{2}Li_0^2$$

Thus, an inductor may store energy in its magnetic field.

41 In the circuit of figure, the bulb will become suddenly bright, if **[CBSE AIPMT 1989]**



(a) contact is made or broken
(b) contact is made
(c) contact is broken
(d) None of the above

Ans. *(c)*

When the contact is suddenly broken, self induced current flow in the direction of main current. Therefore, the bulb B will become suddenly bright.

42 Energy in a current carrying coil is stored in the form of **[CBSE AIPMT 1988]**

(a) electric field
(b) magnetic field
(c) dielectric strength
(d) heat

Ans. *(b)*

Energy stored in a current carrying coil is in the form of magnetic field. Total work done by the external source in building up current from zero to i_0 is

$$W = \frac{1}{2}Li_0^2$$

where, L is self-inductance of coil.

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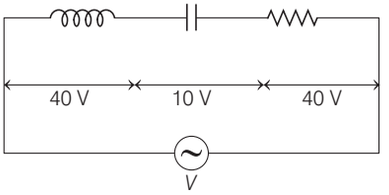
21

Alternating Current (AC)

TOPIC 1
AC-Circuits and Power in AC-Circuits

01 An inductor of inductance L, a capacitor of capacitance C and a resistor of resistance R are connected in series to an AC source of potential difference V volts as shown in figure.

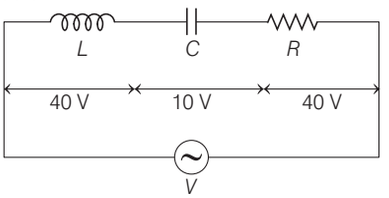


Potential difference across L, C and R is 40 V, 10 V and 40 V, respectively. The amplitude of current flowing through L-C-R series circuit is $10\sqrt{2}$ A. The impedance of the circuit is **[NEET 2021]**

(a) $4\sqrt{2}\ \Omega$ (b) $5\sqrt{2}\ \Omega$
(c) $4\ \Omega$ (d) $5\ \Omega$

Ans. *(d)*

The given circuit diagram as shown below



Given,

$V_L = 40$ V, $V_C = 10$ V and $V_R = 40$ V

The amplitude of the current flowing in the L-C-R series circuit,

$$I_0 = 10\sqrt{2}\ \text{A} \qquad \text{...(i)}$$

We know that, rms current in the L-C-R series circuit,

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

$$\Rightarrow \quad I_{rms} = \frac{10\sqrt{2}}{\sqrt{2}} \quad [\text{from Eq. (i)}]$$

$$\Rightarrow \quad I_{rms} = 10\ \text{A}$$

$$\therefore \quad V_{rms} = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$\Rightarrow \quad V_{rms} = \sqrt{(40)^2 + (40 - 10)^2}$$

$$\Rightarrow \quad V_{rms} = 50\ \text{V}$$

The impedance of the L-C-R series circuit,

$$Z = \frac{V_{rms}}{I_{rms}} \Rightarrow Z = \frac{50\ \text{V}}{10\ \text{A}} \text{ or } Z = 5\Omega$$

02 A series L-C-R circuit containing 5.0 H inductor, 80 μF capacitor and 40 Ω resistor is connected to 230 V variable frequency AC source. The angular frequencies of the source at which power transferred to the circuit is half the power at the resonant angular frequency are likely to be **[NEET 2021]**

(a) 25 rad/s and 75 rad/s
(b) 50 rad/s and 25 rad/s
(c) 46 rad/s and 54 rad/s
(d) 42 rad/s and 58 rad/s

Ans. *(c)*

Given, in the L-C-R series circuit, $L = 5\,\text{H}$,

$$C = 80\,\mu\text{F},\ R = 40\ \Omega$$

Supply voltage, $V = 230$ V

We know that, resonance frequency,

$$\omega_r = \frac{1}{\sqrt{LC}}$$

Substituting the values in the above equation, we get

$$\omega_r = \frac{1}{\sqrt{5 \times 80 \times 10^{-6}}} = 50\ \text{rad/s}$$

Therefore, the angular frequencies of the source at which power transferred to the circuit is half the power at the resonant angular frequency are

$$\omega = \omega_r \pm \Delta\omega \qquad \text{...(i)}$$

We know that,

$$\Delta\omega = \frac{R}{2L} \Rightarrow \Delta\omega = \frac{40}{2(5)} \Rightarrow \Delta\omega = 4$$

Using the Eq. (i), we get

$$\omega = \omega_r \pm \Delta\omega$$

$$\omega = (50 \pm 4)\ \text{rad/s}$$

So, the angular frequency is likely to be 46 rad/s and 54 rad/s.

03 A series L-C-R circuit is connected to an AC voltage source. When L is removed from the circuit, the phase difference between current and voltage is $\frac{\pi}{3}$. If instead C is removed from the circuit, the phase difference is again $\frac{\pi}{3}$ between current and voltage. The power factor of the circuit is **[NEET (Sep.) 2020]**

(a) 0.5 (b) 1.0
(c) –1.0 (d) zero

Ans. *(b)*

For L-C-R circuit, phase difference,

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

When L is removed, then $X_L = 0$

$$\therefore \quad \phi = \tan^{-1}\left(\frac{-X_C}{R}\right)$$

$$\Rightarrow \quad \tan\phi = \left|\frac{X_C}{R}\right| \qquad \text{...(i)}$$

When C is removed, then $X_C = 0$

$$\therefore \quad \phi = \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$\Rightarrow \quad \tan\phi = \frac{X_L}{R} \qquad \text{...(ii)}$$

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From Eqs. (i) and (ii), we get

$$X_L = X_C$$

$\therefore$ Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$$= R$$

Power factor, $\cos\phi = \frac{R}{Z} = \frac{R}{R} = 1$

Hence, correct option is (b).

04 A 40 μF capacitor is connected to a 200 V, 50 Hz AC supply. The rms value of the current in the circuit is, nearly **[NEET (Sep.) 2020]**

(a) 2.05 A (b) 2.5 A
(c) 25.1 A (d) 1.7 A

Ans. ***(b)***

Given, $C = 40\,\mu F = 40 \times 10^{-6}$ F

$V_{rms} = 200$ V

$\nu = 50$ Hz

As, $X_C = \frac{1}{2\pi\nu C}$

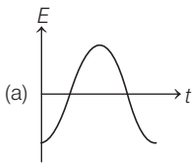
$$= \frac{1}{2\pi \times 50 \times 40 \times 10^{-6}}$$

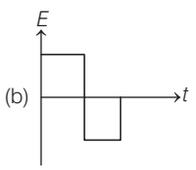
$$= \frac{10^6}{100\pi \times 40} = \frac{250}{\pi}\,\Omega$$

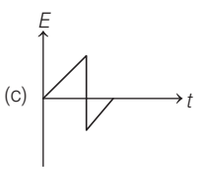
$\therefore$ $I_{rms} = \frac{V_{rms}}{X_C} = \frac{200}{\left(\frac{250}{\pi}\right)} = 2.5$ A

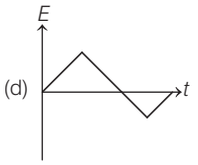
Hence, correct option is (b).

05 The variation of EMF with time for four types of generators are shown in the figures. Which amongst them can be called AC? **[NEET (Odisha) 2019]**









Ans. ***(b)***

The emf generated due to a rotating conductor in a generator is given by

$$E = -\frac{d\phi_B}{dt}$$

where, ϕ_B = magnetic flux linked with conductor

From the above equation we can conclude that the emf generated is a varying function of time with opposite polarity. So, all the graph are correct for the given variations.

06 A circuit when connected to an AC source of 12 V gives a current of 0.2 A. The same circuit when connected to a DC source of 12 V, gives a current of 0.4 A. The circuit is **[NEET (Odisha) 2019]**

(a) series LR (b) series RC
(c) series LC (d) series LCR

Ans. ***(a)***

When the circuit is connected to AC source,

Voltage, $V = 12$ V

Current, $I = 0.2$ A

$\Rightarrow$ Impedance $Z = \frac{V}{I} = \frac{12}{0.2} = 60\ \Omega$

When it is connected to DC source,

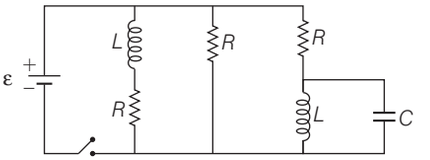
Voltage, $V = 12$ V

Current, $I = 0.4$ A

$\Rightarrow$ Resistance, $R = \frac{V}{I} = \frac{12}{0.4} = 30\,\Omega$

As in case of DC supply, the capacitor act as an open circuit and no current flows through the circuit. So the given circuit will not have capacitor in series combination. Therefore the circuit should be a series L-R circuit.

07 Figure shows a circuit that contains three identical resistors with resistance $R = 9.0\,\Omega$ each, two identical inductors with inductance $L = 2.0$ mH each, and an ideal battery with emf $\varepsilon = 18$ V. The current i through the battery just after the switch closed is **[NEET 2017]**



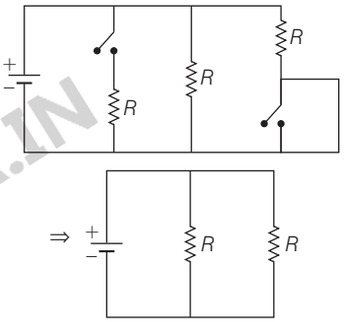
(a) 2 mA (b) 0.2 A
(c) 2 A (d) 0 A

Ans. ***(*)***

No option is matching.

Thinking Process Just after switch is closed, inductor acts like an open switch (open path) and capacitor acts like a closed switch (closed path) because in D.C. circuit inductive resistance becomes zero.

Just after switch is closed, given circuit is equivalent to the circuit shown below.



So, equivalent resistor

$$= \frac{R}{2} = \frac{9}{2}\ \text{ohms}$$

Battery emf, $V = 18$ volts

$\therefore$ Current in circuit $= \frac{V}{R} = \frac{18 \times 2}{9} = 4$ A

08 In an electromagnetic wave in free space the root mean square value of the electric field is $E_{rms} = 6$ V/m. The peak value of the magnetic field is **[NEET 2017]**

(a) 1.41×10^{-8} T (b) 2.83×10^{-8} T
(c) 0.70×10^{-8} T (d) 4.23×10^{-8} T

Ans. ***(b)***

Given, root mean square value of electric field,

$$E_{rms} = 6\ \text{V/m}$$

We know that, peak value of electric field,

$$E_0 = \sqrt{2}\, E_{rms}$$

$\Rightarrow$ $E_0 = \sqrt{2} \times 6$ V/m

Also, we know that, $c = \frac{E_0}{B_0}$

where, c = speed of light in vacuum

B_0 = peak value of magnetic field

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$$\Rightarrow \quad B_0 = \frac{E_0}{c} \Rightarrow B_0 = \frac{\sqrt{2}\times 6}{3\times 10^8}$$

$$\Rightarrow \quad B_0 = \frac{8.48}{3}\times 10^{-8}$$

$$\Rightarrow \quad B_0 = 2.83\times 10^{-8}\ \text{T}$$

09 A small signal voltage $V(t) = V_0 \sin \omega t$ is applied across an ideal capacitor C **[NEET 2016]**

(a) over a full cycle the capacitor C does not consume any energy from the voltage source

(b) current $I(t)$ is in phase with voltage $V(t)$

(c) current $I(t)$ leads voltage $V(t)$ by 180°

(d) current $I(t)$, lags voltage $V(t)$ by 90°

Ans. *(a)*

For an AC circuit containing capacitor only, the phase difference between current and voltage will be $\frac{\pi}{2}$ (i.e. 90°).

In this case current is ahead of voltage by $\frac{\pi}{2}$.

Hence, power in this case is given by

$P = VI\cos\phi$

(ϕ = phase difference between voltage and current)

$$P = VI\cos 90° = 0$$

10 An inductor 20 mH, a capacitor 50 μF and a resistor 40 Ω are connected in series across a source of emf $V = 10\sin 340t$. The power loss in AC circuit is **[NEET 2016]**

(a) 0.67 W (b) 0.76 W

(c) 0.89 W (d) 0.51 W

Ans. *(d)*

Given,

Inductance $L = 20$ mH

Capacitance, $C = 50\ \mu$F

Resistance, $R = 40\ \Omega$

emf, $V = 10\sin 340t$

$\because$ Power loss in AC circuit will be given as

$$P_{av} = I_V^2 R = \left[\frac{E_V}{Z}\right]^2 . R$$

$$= \left(\frac{10}{\sqrt{2}}\right)^2 . 40\ \frac{1}{40^2 + \left(\frac{340\times 20\times 10^3 - 1}{340\times 50\times 10^{-6}}\right)^2}$$

$$= \frac{100}{2}\times 40\times \frac{1}{1600 + (6.8 - 58.8)^2}$$

$$= \frac{2000}{1600 + 2704} \approx 0.46\text{W} \approx 0.51\text{ W}$$

11 Which of the following combinations should be selected for better tuning of an L-C-R circuit used for communication? **[NEET 2016]**

(a) $R = 20\ \Omega$, $L = 1.5$ H, $C = 35\ \mu$F

(b) $R = 25\ \Omega$, $L = 2.5$ H, $C = 45\ \mu$F

(c) $R = 15\ \Omega$, $L = 3.5$ H, $C = 30\ \mu$F

(d) $R = 25\ \Omega$, $L = 1.5$ H, $C = 45\ \mu$F

Ans. *(c)*

Key Idea *For better tuning, peak of current growth must be sharp. This is ensured by a high value of quality factor Q.*

Now, quality factor is given by $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$

From the given options, highest value of Q is associated with $R = 15\ \Omega$, $L = 3.5$ H and $C = 30\ \mu$F

12 The potential differences across the resistance, capacitance and inductance are 80 V, 40 V and 100 V respectively in an L-C-R circuit. The power factor of this circuit is **[NEET 2016]**

(a) 0.4 (b) 0.5

(c) 0.8 (d) 1.0

Ans. *(c)*

Power factor of the L-C-R circuit

$$= \cos\phi = \frac{R}{Z}$$

$$= \frac{IR}{IZ} = \frac{80}{I\sqrt{(X_L - X_C)^2 + R^2}}$$

$$= \frac{80}{\sqrt{(IX_L - IX_C)^2 + (IR)^2}}$$

$$= \frac{80}{\sqrt{(100-40)^2 + (80)^2}}$$

$$= \frac{80}{\sqrt{(60)^2 + (80)^2}} = \frac{80}{100} = 0.8$$

13 A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 220 V source. When the capacitor is 50% charged, the peak value of the displacement current is **[NEET 2016]**

(a) 2.2 A (b) 11 A

(c) 4.4 A (d) $11\sqrt{2}$ A

Ans. *(a)*

Impedence of the R-C circuit,

$$Z = \sqrt{R^2 + X_C^2}$$

where, $R = 100\ \Omega$ and $X_C = 100\ \Omega$

$$\Rightarrow \quad \tau = \sqrt{(100)^2 + (100)^2} = 100\sqrt{2}\ \Omega$$

Peak value of the current,

$$I_{max} = \frac{V_{max}}{Z} = \frac{220\sqrt{2}}{100\sqrt{2}} = 2.2\text{ A}$$

14 A resistance 'R' draws power 'P' when connected to an AC source. If an inductance is now placed in series with the resistance, such that the impedance of the circuit becomes 'Z' the power drawn will be **[CBSE AIPMT 2015]**

(a) $P\left(\frac{R}{Z}\right)^2$ (b) $P\sqrt{\frac{R}{Z}}$

(c) $P\left(\frac{R}{Z}\right)$ (d) P

Ans. *(a)*

When a resistor is connected to an AC source. The power drawn will be

$$P = V_{rms}\cdot I_{rms} = V_{rms}\cdot \frac{V_{rms}}{R} \Rightarrow V_{rms}^2 = PR$$

When an inductor is connected in series with the resistor, then the power drawn will be

$$P' = V_{rms}\cdot I_{rms}\cos\phi$$

where, ϕ = phase difference

$$\therefore \quad P' = \frac{V_{rms}^2}{R}\cdot\frac{R^2}{Z^2} = P\cdot R\cdot\frac{R}{Z^2}$$

$$\Rightarrow \quad P' = \frac{P\cdot R^2}{Z^2} = P\left(\frac{R}{Z}\right)^2$$

15 A series R-C circuit is connected to an alternating voltage source. Consider two situations : **[CBSE AIPMT 2015]**

1. When capacitor is air filled.

2. When capacitor is mica filled.

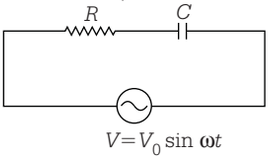
Current through resistor is i and voltage across capacitor is V then

(a) $V_a < V_b$ (b) $V_a > V_b$

(c) $i_a > i_b$ (d) $V_a = V_b$

Ans. *(b)*

Net reactive capacitance,



$$X_C = \frac{1}{2\pi fC}$$

So, current in circuit, $I = \frac{V}{Z}$

$$= \frac{V}{\sqrt{R^2 + \left(\frac{1}{2\pi fC}\right)^2}}$$

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$$\Rightarrow I = \frac{2\pi fC}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}} \times V$$

Voltage drop across capacitor,

$$V_C = I \times X_C$$

$$= \frac{2\pi fC}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}} \times \frac{1}{2\pi fC}$$

$$\text{i.e.} V_C = \frac{V}{\sqrt{4\pi^2 f^2 C^2 R^2 + 1}}$$

When mica is introduced, capacitance will increase hence, voltage across capacitor get decrease.

16 A coil of self-inductance L is connected in series with a bulb B and an AC source. Brightness of the bulb decreases when **[NEET 2013]**

(a) frequency of the AC source is decreased

(b) number of turns in the coil is reduced

(c) a capacitance of reactance $X_C = X_L$ is included in the same circuit

(d) an iron rod is inserted in the coil

Ans. *(d)*

When a bulb of resistance R is connected in series with a coil of self-inductance L, then current in the circuit is given by

$$I = \frac{E}{\sqrt{\omega^2 L^2 + R^2}}$$, where E is the voltage of an AC source

As $$L = \frac{\mu_0 \mu_r N^2 A}{l}$$

$$\Rightarrow L \propto \mu_r$$

When iron rod is inserted, L increases, therefore current I decreases.

17 In an electrical circuit, R, L, C and an AC voltage source are all connected in series. When L is removed from the circuit, the phase difference between the voltage and the current in the circuit is $\pi/3$. If instead, C is removed from the circuit, the phase difference is again $\pi/3$. The power factor of the circuit is **[CBSE AIPMT 2012]**

(a) 1/2

(b) $1/\sqrt{2}$

(c) 1

(d) $\sqrt{3}/2$

Ans. *(c)*

As we know that phase difference for L, C, R series circuit is given by

$$\tan\phi = \frac{X_L - X_C}{R}$$

When L is removed $\tan\frac{\pi}{3} = \frac{X_C}{R}$

$$\sqrt{3} = \frac{X_C}{R}$$

$$\Rightarrow X_C = R\sqrt{3}$$

When C is removed, $\tan\frac{\pi}{3} = \sqrt{3} = \frac{X_L}{R}$

$$\Rightarrow X_L = R\sqrt{3}$$

Hence, in resonant circuit

$$\tan\phi = \frac{\sqrt{3}R - \sqrt{3}R}{R} = 0$$

So, $\phi = 0$

Power factor, $\cos\phi = 1$

It is the condition of resonance, therefore, phase difference between voltage and current is zero and power factor, $\cos\phi = 1$.

18 In an AC circuit an alternating voltage $e = 200\sqrt{2}\sin 100t$ volt is connected to a capacitor of capacity 1μF. The rms value of the current in the circuit is **[CBSE AIPMT 2011]**

(a) 100 mA (b) 200 mA

(c) 20 mA (d) 10 mA

Ans. *(c)*

Problem Solving Strategy Compare the given equation with the equation of alternating voltage i.e.

$$e = e_m \sin\omega t$$

where, $e_m = e_{rms}$

Given,

emf, $e = 200\sqrt{2}\sin 100t$

and $C = 1\mu F = 1 \times 10^{-6} F$

As $e_{rms} = 200\,V$ and $\omega = 100$

$$\therefore X_C = \frac{1}{\omega C} = \frac{1}{1 \times 10^{-6} \times 100} = 10^4\ \Omega$$

$$i_{rms} = \frac{e_{rms}}{X_C}$$

$$= \frac{200}{10^4} = 2 \times 10^{-2}\ A = 20\ mA$$

19 An AC voltage is applied to a resistance R and an inductor L in series. If R and the inductive reactance are both equal to $3\,\Omega$, the phase difference between the applied voltage and the current in the circuit is **[CBSE AIPMT 2011]**

(a) $\pi/4$ (b) $\pi/2$

(c) zero (d) $\pi/6$

Ans. *(a)*

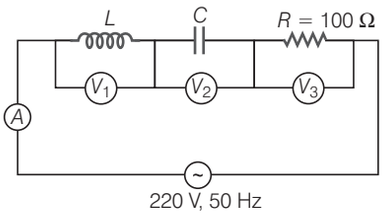
As we know that

$$\tan\phi = \frac{X_L}{R} = \frac{\omega L}{R} \Rightarrow \tan\phi = \frac{3}{3}$$

$$\therefore \tan\phi = 1 \Rightarrow \phi = 45°$$

So, phase difference $= \frac{\pi}{4}$ rad

20 In the given circuit, the reading of voltmeter V_1 and V_2 are 300 V each. The reading to the voltmeter V_3 and ammeter A are respectively **[CBSE AIPMT 2010]**



(a) 150 V, 2.2 A (b) 220 V, 2.2 A

(c) 220 V, 2.0 A (d) 100 V, 2.0 A

Ans. *(b)*

For series LCR circuit

Voltage $V = \sqrt{V_R^2 + (V_L - V_C)^2}$

Since, $V_L = V_C$

Hence $V = V_R = 220\,V$

Also, current $i = \frac{V}{R} = \frac{220}{100} = 2.2\,A$

21 Power dissipated in an L-C-R series circuit connected to an AC source of emf ε is **[CBSE AIPMT 2009]**

(a) $$\frac{\varepsilon^2 R}{\left[R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2\right]}$$

(b) $$\frac{\varepsilon^2 \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}{R}$$

(c) $$\frac{\varepsilon^2 \left[R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2\right]}{R}$$

(d) $$\frac{\varepsilon^2 R}{\sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2}}$$

Ans. *(a)*

Power dissipated in series LCR.

$$P = I_{rms}^2 R$$

$$= \frac{\varepsilon_{rms}^2 R}{|Z|^2} = \frac{\varepsilon^2 R}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]}$$

As $I_{rms} = \frac{V_{rms}}{Z}$

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22 What is the value of inductance L for which the current is maximum in a series LCR circuit with $C = 10\mu F$ and $\omega = 1000\ s^{-1}$?
[CBSE AIPMT 2007]

(a) 100 mH
(b) 1 mH
(c) Cannot be calculated unless R is known
(d) 10 mH

Ans. *(a)*

Current in LCR series circuit,

$$i = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

where, V is rms value of voltage R is resistance, X_L is inductive reactance and X_C is capacitive reactance.

For current to be maximum, denominator should be minimum which can be done, i.e. during the resonance of series LCR circuit

$$X_L = X_C \quad \text{i.e.} \quad \omega L = \frac{1}{\omega C}$$

or $$L = \frac{1}{\omega^2 C} \qquad ...(i)$$

Given, $\omega = 1000\ s^{-1}, C = 10\ \mu F = 10 \times 10^{-6}$ F

Hence, $L = \frac{1}{(1000)^2 \times 10 \times 10^{-6}}$

$= 0.1$ H $= 100$ mH

23 A coil of inductive reactance 31 Ω has a resistance of 8Ω. It is placed in series with a condenser of capacitative reactance 25 Ω. The combination is connected to an AC source of 110 V. The power factor of the circuit is
[CBSE AIPMT 2006]

(a) 0.56 (b) 0.64
(c) 0.80 (d) 0.33

Ans. *(c)*

Power factor of AC circuit is given by

$$\cos\phi = \frac{R}{Z} \qquad ...(i)$$

where, R is resistance and Z is the impedance of the circuit and is given by

$$Z = \sqrt{R^2 + (X_L - X_C^2)} \qquad ...(ii)$$

X_L = inductive reactance
X_C = capacitive reactance
Eqs. (i) and (ii) meet to give,

$$\cos\phi = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} \qquad ...(iii)$$

Given, $R = 8\Omega, X_L = 31\Omega, X_C = 25\ \Omega$

$$\cos\phi = \frac{8}{\sqrt{(8)^2 + (31-25)^2}} = \frac{8}{\sqrt{64+36}}$$

Hence, $\cos\phi = 0.80$

24 In a circuit, L, C and R are connected in series with an alternating voltage source of frequency f. The current leads the voltage by 45°. The value of C is
[CBSE AIPMT 2005]

(a) $\frac{1}{2\pi f(2\pi fL + R)}$
(b) $\frac{1}{\pi f(2\pi fL + R)}$
(c) $\frac{1}{2\pi f(2\pi fL - R)}$
(d) $\frac{1}{\pi f(2\pi fL - R)}$

Ans. *(c)*

Phase difference between current and voltage in LCR series circuit is given by

$$\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$\left[\begin{array}{l} \omega L = \text{inductive reactance} \\ \frac{1}{\omega C} = \text{capacitive reactance} \end{array}\right]$$

ϕ being the angle by which the current leads the voltage.

Given,

$$\phi = 45°$$

$$\therefore \quad \tan 45° = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$\Rightarrow \quad 1 = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$\Rightarrow \quad R = \omega L - \frac{1}{\omega C}$$

$$\Rightarrow \quad \omega C = \frac{1}{(\omega L - R)}$$

$$\Rightarrow \quad C = \frac{1}{\omega(\omega L - R)}$$

$$= \frac{1}{2\pi f(2\pi fL - R)}$$

25 For a series LCR circuit, the power loss at resonance is
[CBSE AIPMT 2002]

(a) $\frac{V^2}{\omega L - \frac{1}{\omega C}}$ (b) $i^2 C\omega$
(c) $i^2 R$ (d) $\frac{V^2}{\omega C}$

Ans. *(c)*

In series LCR circuit at resonance,
capacitive reactance (X_C)
= inductive reactance (X_L)

i.e. $\frac{1}{\omega C} = \omega L$

Total impedance of the circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

i.e. $Z = R$

So, power factor, $\cos\phi = \frac{R}{Z} = \frac{R}{R} = 1$

Thus, power loss at resonance is given by

$$P = V_{rms}\, i_{rms} \cos\phi \qquad [\cos\phi = 1]$$
$$= V_{rms}\, i_{rms} \times 1$$
$$= (i_{rms}\, R)\, i_{rms}$$
$$= (i_{rms})^2\ R = i^2 R$$

26 The reactance of a capacitor of capacitance C is X. If both the frequency and capacitance be doubled, then new reactance will be
[CBSE AIPMT 2001]

(a) X (b) $2X$ (c) $4X$ (d) $\frac{X}{4}$

Ans. *(d)*

If a capacitor of capacitance C is connected with an AC signal, then reactance of that circuit is purely capacitive.

The capacitive reactance is

$$X = \frac{1}{\omega C} = \frac{1}{2\pi fC} \qquad (\omega = 2\pi f)$$

or $$X \propto \frac{1}{fC}$$

Considering two different situations of frequency and capacitance, we have

$$\frac{X'}{X} = \frac{fC}{f'C'} = \frac{f \times C}{2f \times 2C}$$

$[\because f' = 2f \text{ and } C' = 2C]$

or $$\frac{X'}{X} = \frac{1}{4} \quad \text{or} \quad X' = \frac{X}{4}$$

27 A wire of resistance R is connected in series with an inductor of reactance ωL. Then quality factor of RL circuit is **[CBSE AIPMT 2000]**

(a) $\frac{R}{\omega L}$
(b) $\frac{\omega L}{R}$
(c) $\frac{R}{\sqrt{R^2 + \omega^2 L^2}}$
(d) $\frac{\omega L}{\sqrt{R^2 + \omega^2 L^2}}$

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Ans. *(b)*

We define the quality factor of the circuit as follows

Quality factor, Q

$$= 2\pi \times \frac{\text{total energy stored in the circuit}}{\text{loss in energy in each cycle}}$$

But the total energy stored in circuit $= Li_{rms}^2$

and the energy loss per second $= i_{rms}^2 R$

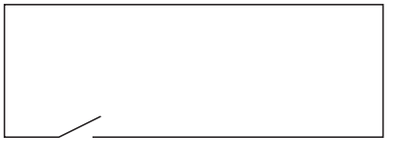
So, loss in energy per cycle $= \frac{i_{rms}^2 R}{f}$

Hence, quality factor,

$$Q = 2\pi \times \frac{Li_{rms}^2}{i_{rms}^2 R/f}$$

$$= \frac{2\pi fL}{R} = \frac{\omega L}{R}$$

28 In a circuit inductance L and capacitance C are connected as shown in figure. A_1 and A_2 are ammeters. When key K is pressed to complete the circuit, then just after closing key (K), the reading of current will be **[CBSE AIPMT 1999]**



(a) zero in both A_1 and A_2
(b) maximum in both A_1 and A_2
(c) zero in A_1 and maximum in A_2
(d) maximum in A_1 and zero in A_2

Ans. *(d)*

There is no DC current in inductive circuit because it does not allow DC current to flow and maximum DC current in capacitive circuit. Hence, the current is zero in A_2 and maximum in A_1.

29 In an AC circuit with voltage V and current i the power dissipated is **[CBSE AIPMT 1997]**

(a) Depends on the phase between V and i
(b) $\frac{1}{\sqrt{2}} Vi$
(c) $\frac{1}{2} Vi$
(d) Vi

Ans. *(a)*

In an AC circuit with voltage V and current i, the power dissipated is given by

$$P = Vi \cos\phi$$

where, ϕ is the phase and $\cos\phi$ is the power factor. Thus, the power dissipated, depends upon the phase between voltage V and current i.

30 In an experiment, 200 V AC is applied at the ends of an LCR circuit. The circuit consists of an inductive reactance (X_L) = 50 Ω, capacitive reactance (X_C) = 50 Ω and ohmic resistance (R) = 10 Ω. The impedance of the circuit is **[CBSE AIPMT 1996]**

(a) 10 Ω (b) 20 Ω
(c) 30 Ω (d) 40 Ω

Ans. *(a)*

Total effective resistance of LCR circuit is called impedance of the LCR series circuit. It is represented by Z.

where $$Z = \frac{V_0}{i_0} = \sqrt{R^2 + (X_L - X_C)^2}$$

Given, $V_{AC} = 200$ V

Resistance offered by inductor

$X_L = 50\ \Omega$

Resistance offered by capacitance

$X_C = 50\ \Omega$

$R = 10\ \Omega$

$Z = ?$

$$\therefore \quad Z = \sqrt{(10)^2 + (50 - 50)^2}$$

or $Z = 10\ \Omega$

31 An LCR series circuit is connected to a source of alternating current. At resonance, the applied voltage and the current flowing through the circuit will have a phase difference of **[CBSE AIPMT 1994]**

(a) π (b) $\frac{\pi}{2}$
(c) $\frac{\pi}{4}$ (d) zero

Ans. *(d)*

A circuit in which inductance L, capacitance C and resistance R are connected in series, and the circuit admits maximum current corresponding to a given frequency of AC is called series resonance circuit. The impedance (Z) of an RLC circuit is given by

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

At resonance $X_L = X_C$

i.e. $\omega L = \frac{1}{\omega C}$, $Z = R$

So, circuit behaves as if it contains R only. So, phase difference = 0.

Frequency of resonating LCR circuit is given by

$$\omega^2 = \frac{1}{LC} \Rightarrow f = \frac{1}{2\pi\sqrt{LC}}$$

32 In an AC circuit, the rms value of current, i_{rms} is related to the peak current, i_0 by the relation **[CBSE AIPMT 1994]**

(a) $i_{rms} = \sqrt{2}\, i_0$ (b) $i_{rms} = \pi i_0$
(c) $i_{rms} = \frac{i_0}{\pi}$ (d) $i_{rms} = \frac{1}{\sqrt{2}} i_0$

Ans. *(d)*

Root mean square value of an alternating current is defined as the square root of the average of i^2, during a complete cycle it may be taken by

$$\overline{i^2} = \frac{\int_0^{2\pi/\omega} i^2\, dt}{\frac{2\pi}{\omega}}$$

$$= \frac{\int_0^{2\pi/\omega} i_0^2 \sin^2 \omega t\, dt}{\frac{2\pi}{\omega}}$$

$$= \frac{i_0^2 \omega}{2\pi} \int_0^{2\pi/\omega} \frac{1}{2}(1 - \cos 2\omega t)\, dt$$

$$= \frac{i_0^2 \omega}{4\pi}\left[t - \frac{\sin 2\omega t}{2\omega}\right]_0^{2\pi/\omega}$$

$$= \frac{i_0^2 \omega}{4\pi}\left(\frac{2\pi}{\omega}\right) = \frac{i_0^2}{2}$$

$$\therefore \quad i_{rms} = \sqrt{\overline{i^2}} = \frac{i_0}{\sqrt{2}}$$

33 The time constant of C-R circuit is **[CBSE AIPMT 1992]**

(a) $\frac{1}{CR}$ (b) $\frac{C}{R}$
(c) CR (d) $\frac{R}{C}$

Ans. *(c)*

The quantity $\tau = CR$ is called time constant or capacitive time constant of CR circuit. This is because dimensions of RC are those of time and for a given CR circuit, its value is constant.

Alternative

As $R = \frac{V}{i}$ and $C = \frac{q}{V}$

$$\therefore \quad RC = \frac{V}{i}\frac{q}{V} = \frac{q}{i} = \frac{i \times t}{i} = t$$

$$\therefore \quad [RC] = [t] = [T]$$

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TOPIC 2
AC Generator and Transformer

34 A step down transformer connected to an AC mains supply of 220 V is made to operate at 11 V, 44 W lamp. Ignoring power losses in the transformer, what is the current in the primary circuit ? **[NEET 2021]**

(a) 0.2 A (b) 0.4 A
(c) 2 A (d) 4 A

Ans. *(a)*

Given, the main supply line voltage in transformer,

$V = 220$ V

The rating of the lamp = 11 V, 44 W

We know that,

$P = VI_P$ ...(i)

Here, P is the power that operates the lamp,

V is the supply line voltage,

I_P is the primary current in the transformer.

From Eq. (i), we get

$\Rightarrow \quad 44 = I_P \times 220$

$\Rightarrow \quad I_P = 0.2\,\text{A}$

35 A transformer having efficiency of 90% is working on 200 V and 3 kW power supply. If the current in the secondary coil is 6 A, the voltage across the secondary coil and the current in the primary coil respectively are **[CBSE AIPMT 2014]**

(a) 300 V, 15 A (b) 450 V, 15 A
(c) 450 V, 13.5 A (d) 600 V, 15 A

Ans. *(b)*

Initial power = 3000 W

As efficiency is 90%, then final power

$= 3000 \times \frac{90}{100} = 2700$ W

$\Rightarrow \quad \left.\begin{matrix} V_1 I_1 = 3000\,\text{W} \\ V_2 I_2 = 2700\ \text{W} \end{matrix}\right\}$ ...(i)

$V_2 = \frac{2700}{6} = \frac{900}{2} \quad [\because I_1 = 6\,\text{A}]$

$\Rightarrow \quad V_2 = 450\,\text{V}$

and $I_1 = \frac{3000}{200} \quad [\because V_1 = 200\,\text{V}]$

$\Rightarrow \quad I_1 = 15\,\text{A}$

36 A 220 V input is supplied to a transformer. The output circuit draws a current of 2.0 A at 440 V. If the efficiency of the transformer is 80%, the current drawn by the primary windings of the transformer is **[CBSE AIPMT 2010]**

(a) 3.6 A (b) 2.8 A
(c) 2.5 A (d) 5.0 A

Ans. *(d)*

Efficiency is defined as the ratio of output power and input power

i.e $\eta\% = \frac{P_{\text{out}}}{P_{\text{input}}} \times 100 = \frac{V_s i_s}{V_p i_p} \times 100$

$80 = \frac{2 \times 440}{220 \times i_p} \times 100 \Rightarrow i_p = 5\text{A}$

37 In an AC circuit the emf (V) and the current (i) at any instant are given respectively by

$V = V_0 \sin\omega t,$

$i = i_0 \sin(\omega t - \phi)$

The average power in the circuit over one cycle of AC is **[CBSE AIPMT 2008]**

(a) $\frac{V_0 i_0}{2}$ (b) $\frac{V_0 i_0}{2}\sin\phi$

(c) $\frac{V_0 i_0}{2}\cos\phi$ (d) $V_0 i_0$

Ans. *(c)*

$P_{av} = V_{rms} \cdot i_{rms} \cos\phi = \frac{1}{2} V_0 i_0 \cos\phi$

$\left[\because V_{rms} = \frac{V_0}{\sqrt{2}}, i_{rms} = \frac{i_0}{\sqrt{2}}\right]$

where, $\cos\phi$ = power factor

38 A transformer is used to light a 100 W and 110 V lamp from a 220 V mains. If the main current is 0.5 A, the efficiency of the transformer is approximately **[CBSE AIPMT 2007]**

(a) 30% (b) 50%
(c) 90% (d) 10%

Ans. *(c)*

The efficiency of transformer

$= \frac{\text{Energy obtained from the secondary coil}}{\text{Energy given to the primary coil}}$

or $\eta = \frac{\text{Output power}}{\text{Input power}}$

or $\eta = \frac{V_s I_s}{V_p I_p} \quad [\text{as power} = VI]$

Given, $V_s I_s = 100$ W, $V_p = 220$ V, $I_p = 0.5$ A

Hence, $\eta = \frac{100}{220 \times 0.5} = 0.90 = 90\%$

39 The primary and secondary coils of a transformer have 50 and 1500 turns respectively. If the magnetic flux ϕ linked with the primary coil is given by $\phi = \phi_0 + 4t$, where ϕ is in weber, t is time in second and ϕ_0 is a constant, the output voltage across the secondary coil is **[CBSE AIPMT 2007]**

(a) 90 V (b) 120 V
(c) 220 V (d) 30 V

Ans. *(b)*

The magnetic flux linked with the primary coil is given by

$\phi = \phi_0 + 4t$

So, voltage across primary

$V_p = \frac{d\phi}{dt} = \frac{d}{dt}(\phi_0 + 4t)$

$= 4$ V (as ϕ_0 = constant)

Also, we have

$N_p = 50$ and $N_s = 1500$

As we know that voltage across primary and secondary coil is directly proportional to the no. of turns in primary and secondary coil respectively.

So, $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ or $V_s = V_p \frac{N_s}{N_p}$

$= 4\left(\frac{1500}{50}\right) = 120$ V

Note As in case of given transformer, voltage in secondary is increased, hence it is a step-up transformer.

40 The core of a transformer is laminated because **[CBSE AIPMT 2006]**

(a) energy losses due to eddy currents may be minimised
(b) the weight of the transformer may be reduced
(c) rusting of the core may be prevented
(d) ratio of voltage in primary and secondary may be increased

Ans. *(a)*

When magnetic flux linked with a coil changes, induced emf is produced in it and the induced current flows through the wire forming the coil. In 1895, Focault experimentally found that these induced currents are set up in the conductor in the form of closed loops. These currents look like eddies or whirlpools and likewise are known as eddy curents. They are also known as

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Focault's current. These currents oppose the cause of their origin, therefore, due to eddy currents, a great amount of energy is wasted in form of heat energy. If core of transformer is laminated, then their effect can be minimised.

41 A step-up transformer operates on a 230 V line and supplies current of 2 A to a load. The ratio of the primary and secondary windings is 1 : 25. The current in the primary coil is **[CBSE AIPMT 1998]**

(a) 15 A (b) 50 A
(c) 25 A (d) 12.5 A

Ans. *(b)*

As change in flux of primary and secondary coil is proportional to the no. of turns in primary and secondary coil respectively.

So, $\frac{\phi_p}{N_p} = \frac{\phi_s}{N_s}$

or $\frac{1}{N_p} \cdot \frac{d\phi_p}{dt} = \frac{1}{N_s} \frac{d\phi_s}{dt}$

$\therefore \quad \frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \left(\text{as } V \propto \frac{d\phi}{dt}\right)$

For no loss of power,

$Vi = \text{constant}$

$\therefore \quad i = \frac{1}{V} \times \text{constant}$

or $\frac{i_p}{i_s} = \frac{V_s}{V_p}$ or $\frac{i_p}{i_s} = \frac{N_s}{N_p}$

i_p and i_s are currents in primary and secondary coils

Here, $\frac{N_p}{N_s} = \frac{1}{25}$

$i_s = 2 \text{ A}$

$\therefore \quad \frac{i_p}{2} = \frac{25}{1}$

or $i_p = 25 \times 2 = 50 \text{ A}$

42 The primary winding of transformer has 500 turns whereas its secondary has 5000 turns. The primary is connected to an AC supply of 20 V-50 Hz. The secondary will have an output of **[CBSE AIPMT 1997]**

(a) 2 V, 5 Hz (b) 200 V, 500 Hz
(c) 2 V, 50 Hz (d) 200 V, 50 Hz

Ans. *(d)*

The transformer converts AC high voltage into AC low voltage, but it does not cause any change in frequency.

The ratio of voltage across input with output voltage is given by

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

N_s = No. of turns in secondary coil
N_p = No. of turns in primary coil
Making substitution, we obtain

$$V_s = \frac{N_s}{N_p} V_p$$

$$= \frac{5000}{500} \times 20 = 200 \text{ V}$$

Thus, output has voltage 200 V and frequency 50 Hz.

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22

Electromagnetic Waves

TOPIC 1
Displacement Current and Properties of EM Waves

01 A capacitor of capacitance C, is connected across an AC source of voltage V, given by

$$V = V_0 \sin\omega t$$

The displacement current between the plates of the capacitor, would then be given by **[NEET 2021]**

(a) $I_d = V_0\, \omega C \cos\omega t$

(b) $I_d = \dfrac{V_0}{\omega C}\cos\omega t$

(c) $I_d = \dfrac{V_0}{\omega C}\sin\omega t$

(d) $I_d = V_0 \omega C \sin\omega t$

Ans. *(a)*

Given, AC source voltage,

$$V = V_0 \sin\omega t \quad ...(i)$$

We know that,

$$Q = CV \quad ...(ii)$$

Here, Q is the charge on the capacitor, C is the capacitance of the capacitor, V is the AC source voltage.

On differentiate Eq. (ii) w.r.t. time, we get

$$\frac{dQ}{dt} = \frac{d(CV)}{dt}$$

$$\Rightarrow \frac{dQ}{dt} = \frac{Cd(V_0 \sin\omega t)}{dt} \quad [\text{from Eq. (i)}]$$

$$\Rightarrow \frac{dQ}{dt} = C\omega V_0 \cos\omega t$$

As we know, the displacement current,

$$I_d = \frac{dQ}{dt}$$

$$\Rightarrow \quad I_d = V_0\, \omega C \cos\omega t$$

02 For a plane electromagnetic wave propagating in x-direction, which one of the following combination gives the correct possible directions for electric field (E) and magnetic field (B) respectively? **[NEET 2021]**

(a) $\hat{\mathbf{j}}+\hat{\mathbf{k}}, \hat{\mathbf{j}}+\hat{\mathbf{k}}$ (b) $-\hat{\mathbf{j}}+\hat{\mathbf{k}}, -\hat{\mathbf{j}}-\hat{\mathbf{k}}$

(c) $\hat{\mathbf{j}}+\hat{\mathbf{k}}, -\hat{\mathbf{j}}+\hat{\mathbf{k}}$ (d) $-\hat{\mathbf{j}}+\hat{\mathbf{k}}, -\hat{\mathbf{j}}+\hat{\mathbf{k}}$

Ans. *(b)*

We know that, in electromagnetic wave, the electric field (E) and magnetic field (B) are perpendicular to each other,

$$\mathbf{E}\cdot\mathbf{B} = 0$$

Consider the option (a);

$$(\hat{\mathbf{j}}+\hat{\mathbf{k}})\cdot(\hat{\mathbf{j}}+\hat{\mathbf{k}}) = 1+1 = 2 \neq 0$$

So, it is incorrect option.

Consider the option (b);

$$(-\hat{\mathbf{j}}+\hat{\mathbf{k}})\cdot(-\hat{\mathbf{j}}-\hat{\mathbf{k}}) = 1-1 = 0$$

Hence, it satisfies the condition $\mathbf{E}\cdot\mathbf{B} = 0$

Similarly, options (c) and (d) are incorrect.

So, the correct option is (b).

03 The magnetic field in a plane electromagnetic wave is given by $B_y = 2\times10^{-7} \sin(\pi\times10^3 x + 3\pi\times10^{11} t)\,\text{T}$ Calculate the wavelength. **[NEET (Oct.) 2020]**

(a) $\pi\times10^3$ m (b) 2×10^{-3} m

(c) 2×10^3 m (d) $\pi\times10^{-3}$ m

Ans. *(b)*

Magnetic field in plane electromagnetic wave is given as

$B_y = 2\times10^{-7} \sin(\pi\times10^3 x + 3\pi\times10^{11} t)\,\mathbf{T}$

Comparing with, $B_y = B_0 \sin(kx - \omega t)$, we get

$$k = \pi\times10^3 \Rightarrow \frac{2\pi}{\lambda} = \pi\times10^3$$

$$\Rightarrow \quad \lambda = \frac{2}{10^3} = 2\times10^{-3}\,\text{m}$$

04 The ratio of contributions made by the electric field and magnetic field components, to the intensity of an electromagnetic wave is (where, c = speed of electromagnetic waves) **[NEET (Sep.) 2020]**

(a) 1 : 1 (b) 1 : c (c) 1 : c^2 (d) c : 1

Ans. *(d)*

We know that,

$$\frac{E_0}{B_0} = c$$

where, E_0 and B_0 are the peak values of electric field and magnetic field, respectively.

$$\therefore \quad E_0 : B_0 = c : 1$$

Hence, correct option is (d).

05 Light with an average flux of 20 W/cm^2 falls on a non-reflecting surface at normal incidence having surface area 20 cm^2. The energy received by the surface during time span of 1 min is **[NEET (Sep.) 2020]**

(a) 12×10^3 J (b) 24×10^3 J

(c) 48×10^3 J (d) 10×10^3 J

Ans. *(b)*

Given, average flux = 20 W/cm^2

Surface area = 20 cm^2

Time = 1 min = 60 s

For non-reflecting surface,

energy received = average flux × surface area × time

$$= 20\times20\times60 = 24\times10^3\,\text{J}$$

06 A parallel plate capacitor of capacitance 20μF is being charged by a voltage source whose potential is changing at the rate of 3 V/s. The conduction current

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through the connecting wires and the displacement current through the plates of the capacitor, would be, respectively.

[NEET (National) 2019]

(a) 60 μA, 60 μA (b) 60 μA, zero
(c) zero, zero (d) zero, 60 μA

Ans. *(a)*

Key Idea The displacement current is precisely equals to the conduction current, when the two are present in different parts of the circuit.

Given, $C = 20\,\mu F = 20 \times 10^{-6}$ F and

$$\frac{dV}{dt} = 3 \text{ V/s}$$

The displacement current in a circuit is given by

$$I_d = \varepsilon_0 \frac{d\phi}{dt}$$

[from Maxwell's equation)

$$= \varepsilon_0 \frac{d}{dt}(EA) \quad [\because \phi = EA]$$

$$= \varepsilon_0 A \frac{d}{dt}\left(\frac{V}{d}\right) \quad [\because V = Ed]$$

$$= \frac{\varepsilon_0 A}{d}\frac{dV}{dt}$$

As the capacitance, $C = \frac{\varepsilon_0 A}{d}$

$$\therefore \quad I_d = C\frac{dV}{dt}$$

Substituting the given values, we get

$$I_d = 20 \times 10^{-6} \times 3$$
$$= 60 \times 10^{-6} \text{ A} = 60\,\mu \text{ A}$$

As displacement current is in between the plates of capacitor and conduction current is in the connecting wires which are equal to each other. So,

$$I_c = I_d = 60\ \mu A$$

07 An EM wave is propagating in a medium with a velocity $\mathbf{v} = v\hat{\mathbf{i}}$. The instantaneous oscillating electric field of this EM wave is along +*y*-axis. Then, the direction of oscillating magnetic field of EM wave will be along **[NEET 2018]**

(a) –*y*-direction (b) +*z*-direction
(c) –*z*-direction (d) –*x*-direction

Ans. *(b)*

Here, velocity of EM wave, $\mathbf{v} = v\hat{\mathbf{i}}$

Instantaneous oscillating electric field,

$$\mathbf{E} = E\hat{\mathbf{j}}$$

As we already know that, during the propagation of = EM waves through a medium oscillating electric and magnetic field vectors are mutually perpendicular to each other and to the direction of each other and to the direction of propagation of the wave ($\mathbf{E} \times \mathbf{B}$).

i.e.

$$\mathbf{E} \times \mathbf{B} = v$$
$$\Rightarrow \quad (E\hat{\mathbf{j}}) \times \mathbf{B} = v\hat{\mathbf{i}} \qquad ...(i)$$

As we know that from vector algebra,

$$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}} \qquad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$$\mathbf{B} = B\hat{\mathbf{k}},$$

where *B* (say) be the magnitude of magnetic field.

Thus, we can say that the direction of oscillating magnetic field of the em wave will be along + *z* direction.

08 Out of the following options which one can be used to produce a propagating electromagnetic wave? **[NEET 2016]**

(a) A stationary charge
(b) A chargeless particle
(c) An accelerating charge
(d) A charge moving at constant velocity

Ans. *(c)*

A particle is known that an electric charge at rest has electric field in the region around it, but no magnetic field. A moving charge produces both the electric and magnetic fields. If a charge is moving with a constant velocity, the electric and magnetic fields will not change with time, hence no EM wave will be produced. But if the charge is moving with a non-zero acceleration, both the electric and magnetic field will change with space and time, it then produces EM wave. This shows that accelerated charge emits electromagnetic waves.

09 A radiation of energy '*E*' falls normally on a perfectly reflecting surface. The momentum transferred to the surface is (*c* = velocity of light)

[CBSE AIPMT 2015]

(a) $\frac{E}{c}$ (b) $\frac{2E}{c}$
(c) $\frac{2E}{c^2}$ (d) $\frac{E}{c^2}$

Ans. *(b)*

The radiation energy is given by

$$E = \frac{hc}{\lambda}$$

Initial momentum of the radiation is

$$\mathbf{P}_i = \frac{h}{\lambda} = \frac{E}{c}$$

The reflected momentum is

$$\mathbf{P}_r = -\frac{h}{\lambda} = -\frac{E}{c}$$

So, the change in momentum of light is

$$\Delta\mathbf{P}_{\text{light}} = \mathbf{P}_r - \mathbf{P}_i = -\frac{2E}{c}$$

Thus, the momentum transferred to the surface is

$$\Delta\mathrm{P}_{\text{light}} = \frac{2E}{c}$$

10 Light with an energy flux of $25 \times 10^4\ \mathbf{Wm}^{-2}$ falls on a perfectly reflecting surface at normal incidence. If the surface area is $\mathbf{15cm}^2$, the average force exerted on the surface is **[CBSE AIPMT 2014]**

(a) 1.25×10^{-6} N (b) 2.50×10^{-6} N
(c) 1.20×10^{-6} N (d) 3.0×10^{-6} N

Ans. *(b)*

As $F_{\text{average}} = \frac{2IA}{c}$

where, I = energy flux of light $= 25 \times 10^4$ Wm^{-2}

A = Surface area of reflecting surface

and c = speed of light $= 3 \times 10^8$ m/s

$$\therefore \ F_{\text{average}} = \frac{2 \times 25 \times 10^4 \times 15 \times 10^{-4}}{3 \times 10^8}$$
$$= 2.50 \times 10^{-6} \text{N}$$

11 The electric field associated with an electro magnetic wave in vacuum is given by $\mathbf{E} = \hat{\mathbf{i}}\,40 \cos(kz - 6 \times 10^8 t)$, where *E*, *z* and *t* are in volt/m, metre and second respectively. The value of wave vector *k* is **[CBSE AIPMT 2012]**

(a) 2 m^{-1} (b) 0.5 m^{-1}
(c) 6 m^{-1} (d) 3 m^{-1}

Ans. *(a)*

Electromagnetic wave equation is given by

$$E = E_0 \cos(kz - \omega t) \qquad ...(i)$$

Speed of electromagnetic wave, $v = \frac{\omega}{k}$

Given, equation is

$$\mathbf{E} = \hat{\mathbf{i}}\,40 \cos(kz - 6 \times 10^8 t) \qquad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$$\omega = 6 \times 10^8 \quad \text{and} \quad E_0 = 40\,\hat{\mathbf{i}}$$

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Here, wave factor,

$$k = \frac{\omega}{v} = \frac{6 \times 10^8}{3 \times 10^8} = 2\ \text{m}^{-1}$$

12 The electric and the magnetic field, associated with an electromagnetic wave, propagating along the +z-axis, can be represented by **[CBSE AIPMT 2011]**

(a) $[\mathbf{E} = E_0\hat{\mathbf{k}}, \mathbf{B} = B_0\hat{\mathbf{i}}]$

(b) $[\mathbf{E} = E_0\hat{\mathbf{j}}, \mathbf{E} = B_0\hat{\mathbf{j}}]$

(c) $[\mathbf{E} = E_0\hat{\mathbf{j}}, \mathrm{B} = B_0\hat{\mathbf{k}}]$

(d) $[\mathbf{E} = E_0\hat{\mathbf{i}}, \mathbf{B} = B_0\hat{\mathbf{j}}]$

Ans. *(d)*

As we know that $\mu = \mathbf{E} \times \mathbf{B} = E_0\hat{\mathbf{i}} + B_0\hat{\mathbf{j}}$

$\mathbf{E} \times \mathbf{B}$ points in the direction of wave propagation.

13 Which of the following statement is false for the properties of electromagnetic waves? **[CBSE AIPMT 2010]**

(a) Both electric and magnetic field vectors attain the maxima and minima at the same place and same time

(b) The energy in electromagnetic wave is divided equally between electric and magnetic vectors

(c) Both electric and magnetic field vectors are parallel to each other and perpendicular to the direction of propagation of wave

(d) These waves do not require any material medium for propagation

Ans. *(c)*

The time varying electric and magnetic fields are mutually perpendicular to each other and also perpendicular to the direction of propagation.

14 The electric field part of an electromagnetic wave in a medium is represented by $E_x = 0$; $E_y = 2.5\frac{N}{C}\cos\left[\left(2\pi \times 10^6\ \frac{\text{rad}}{\text{m}}\right)t - \left(\pi \times 10^{-2}\ \frac{\text{rad}}{\text{s}}\right)x\right]$; $E_z = 0$. The wave is **[CBSE AIPMT 2009]**

(a) moving along y-direction with frequency $2\pi \times 10^6$ Hz and wavelength 200 m

(b) moving along x-direction with frequency 10^6 Hz and wavelength 100 m

(c) moving along x-direction with frequency 10^6 Hz and wavelength 200 m

(d) moving along – x-direction with frequency 10^6 Hz and wavelength 200 m

Ans. *(c)*

Comparing the given equation

$$E_y = 2.5\frac{\text{N}}{\text{C}}\cos\left[\left(2\pi \times 10^6\ \frac{\text{rad}}{\text{m}}\right)t - \left(\pi \times 10^{-2}\ \frac{\text{rad}}{\text{sec}}\right)x\right]$$

With the standard equation

$$E_y = E_0\cos(\omega t - kx)$$

we get $\omega = 2\pi f = 2\pi \times 10^6$

$\therefore \quad f = 10^6$ Hz

Moreover, we know that

$$\frac{2\pi}{\lambda} = k = \pi \times 10^{-2}\ \text{m}^{-1}$$

$\Rightarrow \quad \lambda = 200\text{m}$

As direction of field $\mathbf{E}$ of electromagnetic wave is in y direction so, the wave is moving along positive x-direction with frequency 10^6 Hz and wavelength 200 m.

15 The velocity of electromagnetic wave is along the direction of **[CBSE AIPMT 2002]**

(a) $\mathbf{B} \times \mathbf{E}$ (b) $\mathbf{E} \times \mathbf{B}$

(c) $\mathbf{E}$ (d) $\mathbf{B}$

Ans. *(b)*

An electromagnetic wave is the wave composed of the oscillations of electric and magnetic fields in mutually perpendicular planes and these oscillations are perpendicular to the direction of propagation of wave.

The direction of propagation of electromagnetic wave is given by poynting vector

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} = \frac{\mathbf{E} \times \mathbf{B}}{\mu_0}$$

This is parallel to $\mathbf{E} \times \mathbf{B}$.

16 In a certain region of space electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$ are perpendicular to each other and an electron enters in region perpendicular to the direction of $\mathbf{B}$ and $\mathbf{E}$ both and moves undeflected, then velocity of electron is **[CBSE AIPMT 2001]**

(a) $\frac{|\mathbf{E}|}{|\mathbf{B}|}$ (b) $\mathbf{E} \times \mathbf{B}$ (c) $\frac{|\mathbf{B}|}{|\mathbf{E}|}$ (d) $\mathbf{E} \cdot \mathbf{B}$

Ans. *(a)*

For electron to pass undeflected, electric force on electron = magnetic force on electron

i.e. $eE = evB$

or $v = \frac{E}{B}$ or $v = \frac{|\mathbf{E}|}{|\mathbf{B}|}$

17 The electromagnetic radiations are caused by **[CBSE AIPMT 1999]**

(a) a stationary charge

(b) uniformly moving charges

(c) accelerated charges

(d) All of the above

Ans. *(c)*

A stationary charge produces electric field only; a uniformly moving charge produces localised electromagnetic field.

An accelerated charge produces electro- magnetic radiations. The reason is that due to accelerated charges, magnetic field is produced around accelerating charges. As the velocity of charge changes, the magnetic field produced due to it also changes with time. This varying magnetic field produces the electric field.

The electric field so produced also changes with time. These two varying fields are mutually perpendicular and also perpendicular to the direction of propagation of wave and both the fields are in same phase and of same frequency. The frequency of these fields is same as the frequency of oscillations of the charged particle. The wave associated with these oscillations is called the electromagnetic wave.

18 The wavelength of light of frequency 100 Hz is **[CBSE AIPMT 1999]**

(a) 2×10^6 m (b) 3×10^6 m

(c) 4×10^6 m (d) 5×10^6 m

Ans. *(b)*

The relation between velocity of light (c), frequency (ν) and wavelength (λ) is

$$c = \nu\lambda$$

Thus, wavelength $\lambda = \frac{c}{\nu}$

Given, $c = 3 \times 10^8$ m/s, $\nu = 100$ Hz

$$\therefore \quad \lambda = \frac{3 \times 10^8}{100} = 3 \times 10^6\ \text{m}$$

19 If ε_0 and μ_0 are respectively the electric permittivity and magnetic permeability of free space, ε and μ are the corresponding quantities

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in a medium, the index of refraction of the medium is **[CBSE AIPMT 1997]**

(a) $\sqrt{\frac{\varepsilon_0 \mu_0}{\varepsilon\mu}}$ (b) $\sqrt{\frac{\varepsilon\mu}{\varepsilon_0 \mu_0}}$

(c) $\sqrt{\frac{\varepsilon_0 \mu}{\varepsilon \mu_0}}$ (d) $\sqrt{\frac{\varepsilon}{\varepsilon_0}}$

Ans. *(b)*

Refractive index of medium is given by

$$n = \sqrt{\mu_r \varepsilon_r}.$$

Here, $\mu = \mu_0 \mu_r \Rightarrow \mu_r = \frac{\mu}{\mu_0}$

and $\varepsilon = \varepsilon_0 \varepsilon_r \Rightarrow \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$

$$\therefore \quad n = \sqrt{\frac{\mu}{\mu_0} \cdot \frac{\varepsilon}{\varepsilon_0}} = \sqrt{\frac{\varepsilon\mu}{\varepsilon_0 \mu_0}}$$

20 The oscillating electric and magnetic field vectors of electromagnetic wave are oriented along **[CBSE AIPMT 1995]**

(a) the same direction and in phase

(b) the same direction but have a phase difference of 90°

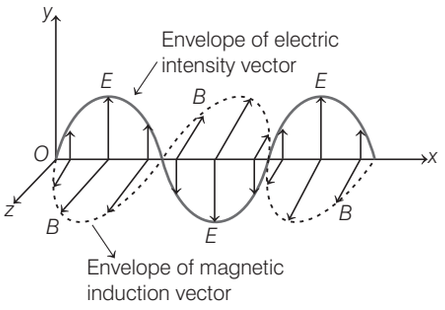
(c) mutually perpendicular directions and are in phase

(d) mutually perpendicular directions but has a phase difference of 90°

Ans. *(c)*

According to Maxwell, the electromagnetic waves are those waves in which there are sinusoidal variations of electric and magnetic field vectors at right angles to each other as well as right angles to the direction of wave propagation. Both these fields vary with time and space and have the same frequency.

In figure, the electric field vector (**E**) and magnetic field vector (**B**) are vibrating along *y* and *z*-directions and propagation of electromagnetic wave is shown in *x*-direction.



From figure it is clear that electric and magnetic fields oscillate in same phase.

TOPIC 2
EM Spectrum

21 The electromagnetic wave with shortest wavelength among the following is **[NEET (Oct.) 2020]**

(a) UV-rays (b) X-rays

(c) γ-rays (d) microwaves

Ans. *(c)*

Gamma-rays has the shortest wavelength because it has higher frequency than UV-rays, microwaves and X-rays.

22 The energy of the EM waves is of the order of 15 keV. To which part of the spectrum does it belong? **[CBSE AIPMT 2015]**

(a) X-rays (b) Infrared rays

(c) Ultravioiet rays (d) γ-rays

Ans. *(a)*

Given, energy of EM waves is of the order of 15 keV

i.e. $E = h\nu = h \times \frac{c}{\lambda}$

$$\Rightarrow \quad \lambda = \frac{h \times c}{E} = \frac{6.624 \times 10^{-34} \times 3 \times 10^{18}}{15 \times 10^3 \times 1.6 \times 10^{-19}}$$

$$= \frac{1.3248 \times 10^{-29}}{1.6 \times 10^{-19}} = 0.828 \times 10^{-10}\,\text{m}$$

$= 0.828$ Å [$\because$ 1Å $= 10^{-10}$ m]

$\lambda = 0.828$ Å

Thus, this spectrum is a part of *X*-rays.

23 The condition under which a microwave oven heats up a food item containing water molecules most efficiently is **[NEET 2013]**

(a) the frequency of the microwave must match the resonant frequency of the water molecules

(b) the frequency of the microwave has no relation with natural frequency of water molecules

(c) microwave are heat waves, so always produce heating

(d) infra-red waves produce heating in a microwave oven

Ans. *(a)*

It is an electromagnetic wave. The frequency of the microwave oven must match the resonant frequency of the water molecules.

Note In the presence of microwaves, water molecules oscillate with frequency of microwaves and large heat is developed.

24 The decreasing order of wavelength of infrared, microwave, ultraviolet and gamma rays is **[CBSE AIPMT 2011]**

(a) gamma rays, ultraviolet, infrared, microwaves

(b) microwaves, gamma rays, infrared, ultraviolet

(c) infrared, microwave, ultraviolet, gamma rays

(d) microwave, infrared, ultraviolet, gamma rays

Ans. *(d)*

Decreasing order of wavelength of various rays is Microwave > Infrared > Ultraviolet > Gamma rays

25 The velocity of electromagnetic radiation in a medium of permittivity ε_0 and permeability μ_0 is given by **[CBSE AIPMT 2008]**

(a) $\sqrt{\frac{\varepsilon_0}{\mu_0}}$ (b) $\sqrt{\mu_0 \varepsilon_0}$ (c) $\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ (d) $\sqrt{\frac{\mu_0}{\varepsilon_0}}$

Ans. *(c)*

The velocity of electromagnetic waves in free space is given by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

26 If λ_v, λ_x and λ_m represent the wavelengths of visible light, X-rays and microwaves respectively, then **[CBSE AIPMT 2005]**

(a) $\lambda_m > \lambda_x > \lambda_v$ (b) $\lambda_v > \lambda_m > \lambda_x$

(c) $\lambda_m > \lambda_v > \lambda_x$ (d) $\lambda_v > \lambda_x > \lambda_m$

Ans. *(c)*

Wavelength order of given rays are listed below

Waves	Wavelength (in Å)
Visible light	4000–7000
X-rays	$10^{-3} - 10^{2}$
Microwaves	$10^{7} - 10^{9}$

So, $\lambda_x < \lambda_v < \lambda_m$

27 Which of the following rays are not electromagnetic waves? **[CBSE AIPMT 2003]**

(a) β-rays (b) Heat rays

(c) X-rays (d) γ-rays

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Ans. *(a)*

(a) β-rays are fast moving electrons. So, they are not electromagnetic waves.

(b) Heat rays can travel through vaccum *via* radiation process. They are electromagnetic waves.

(c) X-rays are electromagnetic waves having wavelengths from about 10^{-8} m to 10^{-12} m.

(d) γ-rays are electromagnetic waves having wavelengths ranging from about 10^{-16} m to 10^{-14} m.

Hence, choice (a) is correct.

28 Which of the following has minimum wavelength ? **[CBSE AIPMT 2002]**

(a) X-rays (b) Ultraviolet rays

(c) γ-rays (d) Cosmic rays

Ans. *(d)*

The wavelength order of waves are given below

Waves	Wavelength (in Å)
(a) X-rays	0.001 Å to 100 Å
(b) Ultraviolet rays	10 Å to 4000 Å
(c) γ-rays	0.0001 Å to 1 Å
(d) Cosmic rays	upto 4×10^{-3} Å

Thus, cosmic rays have the minimum wavelength.

29 What is the cause of "Green house effect"? **[CBSE AIPMT 2002]**

(a) Infrared rays (b) Ultraviolet rays

(c) X-rays (d) Radio-waves

Ans. *(a)*

The green house is a room made of glass which is constructed to grow plants in open space. The glass transmits the infrared radiations of short wavelength and the visible light, but it absorbs the infrared radiations of long wavelength. During the day time, the light and the infrared radiations of short wavelength enter inside the green house through the roof and the walls and they are absorbed by the plants.

At night, plants emit the infrared radiations through the glass walls and roof. As a result, green house remains warm. This is called green house effect.

30 The frequency of γ-rays, X-rays and ultraviolet rays are *a*, *b* and *c* respectively. Then, **[CBSE AIPMT 2000]**

(a) $a > b > c$ (b) $a < b < c$

(c) $a = b = c$ (d) $a > c > b$

Ans. *(a)*

Frequency of radiations given are listed below.

	Waves	Frequency (in Hz)	
1.	γ-rays	(a)	3×10^{21} to 3×10^{18}
2.	X-rays	(b)	3×10^{18} to 3×10^{16}
3.	Ultraviolet radiation	(c)	3×10^{16} to 7.5×10^{14}

Thus, correct order is $a > b > c$.

31 Ozone layer blocks the radiations of wave length **[CBSE AIPMT 1999]**

(a) less than 3×10^{-7} m

(b) equal to 3×10^{-7} m

(c) more than 3×10^{-7} m

(d) All of the above

Ans. *(a)*

Ozone layer extends from 30 km to nearly 50 km above the earth's surface in ozone sphere. This layer absorbs the major part of ultraviolet radiations coming from the sun and does not allow them to reach the earth's surface.

The range of ultraviolet radiations is 100 Å to 4000 Å. Thus, it blocks the radiations of wavelength less than 3×10^{-7} m (or 3000 Å).

32 A signal emitted by an antenna from a certain point can be received at another point of the surface in the form of **[CBSE AIPMT 1993]**

(a) sky wave

(b) ground wave

(c) sea wave

(d) Both (a) and (b)

Ans. *(d)*

Space communication refers to sending, receiving and processing of information through space. Following are the modes of space communication

(i) round or surface wave propagation

(ii) Space wave or tropospheric wave propagation

(iii) Sky wave propagation

(iv) Satellite communication

33 The structure of solids is investigated by using **[CBSE AIPMT 1992]**

(a) cosmic rays

(b) X-rays

(c) γ-rays

(d) infrared radiations

Ans. *(b)*

Due to high penetrating power of X-rays, X-rays are used for investigation of structure of solids. Lane spot method and rotating cylinder method are used for this purpose. X-rays fall on solid under investigation and their structure is received on photographic plate.

34 The frequency of electromagnetic wave, which is best suited to observe a particle of radius 3×10^{-4} cm, is of the order of **[CBSE AIPMT 1991]**

(a) 10^{15} (b) 10^{14} (c) 10^{13} (d) 10^{12}

Ans. *(b)*

Size of particle of any wave is given in terms of wavelength

$$\lambda = \frac{c}{\nu}$$

Here, $\lambda = 3 \times 10^{-4}$ cm,

Velocity of light in vacuum, $c = 3 \times 10^{10}$ cm/s

$$\therefore \quad 3 \times 10^{-4} = \frac{3 \times 10^{10}}{\nu}$$

$\therefore$ Frequency of electromagnetic wave

$$\nu = 10^{14} \text{ Hz}$$

35 Pick out the longest wavelength from the following types of radiations **[CBSE AIPMT 1990]**

(a) blue light (b) gamma rays

(c) X-rays (d) red light

Ans. *(d)*

Gamma rays have wavelength range 6×10^{-14} m to 1×10^{-10} m, X-rays have wavelength range 1×10^{-13} m to 3×10^{-8} m. Blue light and red light lies in visible range of spectrum which extends from 4000Å to 7800 Å. Hence, wavelength of red light is longest.

36 Which of the following is the longest wave ? **[CBSE AIPMT 1989]**

(a) X-rays (b) γ-rays

(c) Microwaves (d) Radiowaves

Ans. *(d)*

Wavelength range of various waves are as follows

Name	Wavelength range (m)
Gamma rays	6×10^{-14} to 1×10^{-10}
X-rays	1×10^{-13} to 3×10^{-8}
Radio waves	greater than 0.1
Microwaves	10^{-3} to 0.3

So, radiowaves are the longest waves.

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23

Ray Optics and Optical Instruments

TOPIC 1
Reflection of Light

01 An object is placed on the principal axis of a concave mirror at a distance of 1.5 f (f is the focal length). The image will be at **[NEET (Oct.) 2020]**

(a) $-3f$ (b) $1.5f$
(c) $-1.5f$ (d) $3f$

Ans. *(a)*

Object distance, $u = -1.5f$

By mirror formula,

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

$$\Rightarrow \frac{1}{v}+\frac{1}{-1.5f}=\frac{1}{-f}$$

$$\Rightarrow \frac{1}{v}=-\frac{1}{f}+\frac{1}{1.5f}$$

$$=\frac{1}{f}\left[-1+\frac{1}{1.5}\right]=\frac{1}{f}\left[-1+\frac{2}{3}\right]$$

$$\Rightarrow \frac{1}{v}=\frac{1}{f}\left(-\frac{1}{3}\right)$$

$$\Rightarrow v=-3f$$

02 An object is placed at a distance of 40 cm from a concave mirror of focal length 15 cm. If the object is displaced through a distance of 20 cm towards the mirror, the displacement of the image will be **[NEET 2018]**

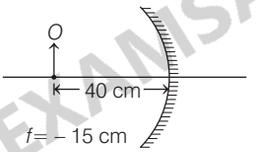
(a) 30 cm towards the mirror
(b) 36 cm away from the mirror
(c) 30 cm away from the mirror
(d) 36 cm towards the mirror

Ans. *(b)*

Key Concept *The net displacement of the images is equal to the difference between the image distance in both the cases.*

Case 1 When the object distance, $u_1 = -40$ cm

Focal length of mirror, $f = -15$ cm



Using the mirror formula, we get

$$\frac{1}{f}=\frac{1}{v_1}+\frac{1}{u_1}$$

Substituting the given values, we get

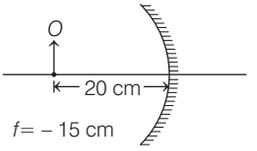
$$-\frac{1}{15}=\frac{1}{v_1}+\left(\frac{-1}{40}\right)$$

$$\Rightarrow \frac{1}{v_1}=\frac{1}{40}-\frac{1}{15}=\frac{3-8}{120}=\frac{-5}{120}$$

$$\Rightarrow v_1=\frac{-120}{5}=-24\text{ cm}$$

Case 2 When the object distance,

$u_2 = 20$ cm



Using the mirror formula, we get

$$\frac{1}{f}=\frac{1}{v_2}+\frac{1}{u_2}$$

Substituting the given values, we get

$$-\frac{1}{15}=\frac{1}{v_2}+\left(-\frac{1}{20}\right)$$

$$\Rightarrow \frac{1}{v_2}=\frac{1}{20}-\frac{1}{15}=\frac{3-4}{60}=\frac{-1}{60}$$

$$\Rightarrow v_2=-60\text{ cm}$$

$\therefore$ The displacement of the image is

$= v_2 - v_1$

$= -60 - (-24) = -60 + 24$

or $= -36$ cm

$= 36$ cm, away from the mirror

03 A beam of light from a source L is incident normally on a plane mirror fixed at a certain distance x from the source. The beam is reflected back as a spot on a scale placed just above the source L. When the mirror is rotated through a small angle θ, the spot of the light is found to move through a distance y on the scale. The angle θ is given by **[NEET 2017]**

(a) $\frac{y}{2x}$ (b) $\frac{y}{x}$
(c) $\frac{x}{2y}$ (d) $\frac{x}{y}$

Ans. *(a)*

According to the question

L = Light source

When the light beams incident normally on the plane mirror, it is reflected back to the point from which it was coming. When the plane mirror is rotated by an angle θ, the reflected ray or beam of light must rotate by angle 2θ, from refraction at plane surface theory.

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04 Match the corresponding entries of Column 1 with Column 2. [Where m is the magnification produced by the mirror] **[NEET 2016]**

	Column 1		Column 2
A.	$m=-2$	a.	Convex mirror
B.	$m=-\frac{1}{2}$	b.	Concave mirror
C.	$m=+2$	c.	Real image
D.	$m=+\frac{1}{2}$	d.	Virtual image

(a) A→ a and c; B→ a and d; C→ a and b; D→ c and d
(b) A→ a and d; B→ b and c; C→ b and d; D→ b and c
(c) A→ c and d; B→ b and d; C→ b and c; D→ a and d
(d) A→ b and c; B→ b and c; C→ b and d; D→ a and d

Ans. *(d)*

A concave mirror forms real and virtual images, whose magnification can be negative or positive depending upon the position of the object.

If object is placed between focus and pole the image obtained will be virtual and its magnification will be positive. In all other cases concave mirror forms real images whose magnification will be negative.

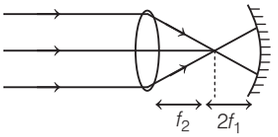
A convex mirror always forms a virtual image whose magnification will always be positive.

05 A concave mirror of focal length f_1 is placed at a distance of d from a convex lens of focal length f_2. A beam of light coming from infinity and falling on this convex lens-concave mirror combination returns to infinity. The distance d must be equal **[CBSE AIPMT 2012]**

(a) f_1+f_2 (b) $-f_1+f_2$
(c) $2f_1+f_2$ (d) $-2f_1+f_2$

Ans. *(c)*

According to question, the ray diagram will be



So, distance d between convex lens and concave mirror is given by

$$d=2f_1+f_2$$

06 A man is 6 ft tall. In order to see his entire image, he requires a plane mirror of minimum length equal to **[CBSE AIPMT 2000]**

(a) 6 ft (b) 12 ft
(c) 2 ft (d) 3 ft

Ans. *(d)*

The minimum size of plane mirror required to see full length of a man

$$=\frac{\text{height of man}}{2}$$

Given, height of man = 6 ft

Thus, minimum size of plane mirror

$$=\frac{6}{2}=3\,\text{ft}$$

07 If two mirrors are kept inclined at 60° to each other and a body is placed at the middle, then total number of images formed, is **[CBSE AIPMT 1995]**

(a) six
(b) five
(c) four
(d) three

Ans. *(b)*

When an object is held in between two plane mirrors M_1 and M_2 inclined at $\angle\theta$, more than one image is formed on account of multiple reflections of light from the mirrors. In general, total number of images (n) formed is given by

$$n=\frac{360°}{\theta}-1$$

Here, $\theta=60°$

$$\therefore \quad n=\frac{360°}{60°}-1=6-1=5$$

08 Ray optics is valid, when characteristic dimensions are **[CBSE AIPMT 1989]**

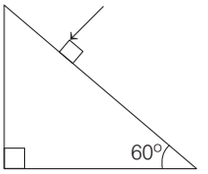
(a) of the same order as the wavelength of light
(b) much smaller than the wavelength of light
(c) of the order of one millimetre
(d) much larger than the wavelength of light

Ans. *(d)*

Ray optics, uses the geometry of straight lines to account for the macroscopic phenomena like rectilinear propagation, reflection, refraction etc. Ray optics can be taken as a limiting case of wave optics. This is primarily because wavelength of light is small.

TOPIC 2
Refraction, TIR and Prism

09 Find the value of the angle of emergence from the prism. Refractive index of the glass is $\sqrt{3}$. **[NEET 2021]**



(a) 60° (b) 30°
(c) 45° (d) 90°

Ans. *(a)*

Given, the refractive index of the glass, $n_2=\sqrt{3}$

The refractive index of the air, $n_1=1$

The path of ray incident on the prism is as shown below

From the given figure, $r_1=0°$

As, $A=r_1+r_2$

where, A is the angle of prism .

$$30°=0°+r_2 \;\Rightarrow\; r_2=30°$$

Using the Snell's law, in glass and air interference,

$n_2\sin\theta_2=n_1\sin\theta_1 \Rightarrow$
$n_2\sin r_2=n_1\sin e$

$$\Rightarrow \quad \sqrt{3}\sin30°=1\times\sin e \;\Rightarrow\; \sin e=\frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad \sin e=\sin60° \;\Rightarrow\; e=60°$$

10 If the critical angle for total internal reflection from a medium to vacuum is 45°, then velocity of light in the medium is **[NEET (Oct.) 2020]**

(a) 1.5×10^8 m/s (b) $\frac{3}{\sqrt{2}}\times10^8$ m/s
(c) $\sqrt{2}\times10^8$ m/s (d) 3×10^8 m/s

Ans. *(b)*

Critical angle, $i_C=45º$

We know that,

$$\mu=\frac{1}{\sin i_C}=\frac{1}{\sin45º}=\frac{1}{1/\sqrt{2}}=\sqrt{2}$$

$$\Rightarrow \quad \mu=\sqrt{2}$$

$$\Rightarrow \quad \frac{\text{Velocity of light in air}}{\text{Velocity of light in medium}}=\sqrt{2}$$

$$\Rightarrow \quad \frac{3\times10^8}{v_m}=\sqrt{2}$$

$$\Rightarrow \quad v_m=\frac{3}{\sqrt{2}}\times10^8\,\text{m/s}$$

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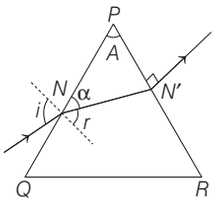
11 A ray is incident at an angle of incidence i on one surface of a small angle prism (with angle of prism A) and emerges normally from the opposite surface. If the refractive index of the material of the prism is μ, then the angle of incidence is nearly equal to **[NEET (Sep.) 2020]**

(a) $\frac{2A}{\mu}$ (b) μA

(c) $\frac{\mu A}{2}$ (d) $\frac{A}{2\mu}$

Ans. *(b)*

According to the question, the ray diagram can be shown as



From figure in $\Delta PNN'$,

$A + \alpha + 90° = 180°$

$\Rightarrow \quad \alpha = 90° - A$ ...(i)

Also, $r + \alpha = 90°$

$\Rightarrow \quad r = 90° - \alpha$

$= 90° - (90° - A) = A$

[$\because$ from Eq. (i)]

$\Rightarrow \quad r = A$

From Snell's law,

$\mu_1 \sin i = \mu_2 \sin r$

$\Rightarrow \quad \sin i = \mu \sin A$

(here, $\mu_1 = 1$ and $\mu_2 = \mu$)

For small angle, $\sin\theta \simeq \theta$

$\Rightarrow \quad i = \mu A$

Hence, correct option is (b).

12 Pick the wrong answer in the context with rainbow. **[NEET (National) 2019]**

(a) The order of colours is reversed in the secondary rainbow

(b) An observer can see a rainbow when his front is towards the sun

(c) Rainbow is a combined effect of dispersion refraction and reflection of sunlight

(d) When the light rays undergo two internal reflections in a water drop, a secondary rainbow is formed

Ans. *(b)*

The necessary conditions for the rainbow to take place is

(i) Sun should be shining in part of the sky while it is raining in opposite part of the sky.

(ii) The observer must stand with his back towards the sun.

$\therefore$ Statement in option (b) is wrong. However, rest statements regarding the rainbow are correct.

13 Which colour of the light has the longest wavelength? **[NEET (National) 2019]**

(a) Blue (b) Green

(c) Violet (d) Red

Ans. *(d)*

Different colours of white light have different wavelengths. The descending order of the wavelength of the component of white light is

$$\lambda_{Red} > \lambda_{Green} > \lambda_{Blue} > \lambda_{Violet}$$

14 In total internal reflection when the angle of incidence is equal to the critical angle for the pair of media in contact, what will be angle of refraction? **[NEET (National) 2019]**

(a) 0º

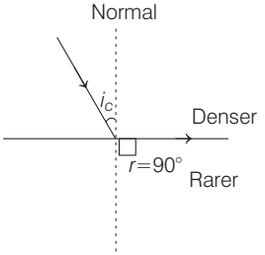
(b) Equal to angle of incidence

(c) 90º

(d) 180º

Ans. *(c)*

The total internal reflection is the phenomenon of reflection back of light in the denser medium when it travel from denser to rarer medium, when the angle of incidence is greater than the critical angle. While the critical angle for a pair of given media in contact is the angle of incidence in denser medium for which the angle of refraction in rarer medium is 90°.

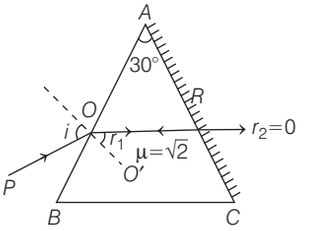


15 The refractive index of the material of a prism is $\sqrt{2}$ and the angle of the prism is 30°. One of the two refracting surfaces of the prism is made a mirror inwards, by silver coating. A beam of monochromatic light entering the prism from the other face will retrace its path (after reflection from the silvered surface) if its angle of incidence on the prism is **[NEET 2018]**

(a) 30° (b) 45° (c) 60° (d) zero

Ans. *(b)*

According to the question, the figure of mentioned prism is given as



(since, there is no refraction at the face AC)

Given,

Refractive index of the material of prism, $\mu = \sqrt{2}$

Angle of prism, $A = 30°$

If the ray OR has to retrace its path after reflection (as per the given condition), then the ray has to fall normally on the surface AC.

This means

$\angle ARO = \angle ORC = 90°$

In ΔAOR,

$\angle AOR + \angle ARO + \angle OAR = 180°$

$\Rightarrow \quad \angle AOR + 90° + 30° = 180°$

$\Rightarrow \quad \angle AOR = 180° - 120° = 60°$ ...(i)

As we know,

$\angle AOR + \angle r_1 = 90°$

$\Rightarrow \angle r_1 = 90° - 60° = 30°$ [from Eq. (i)]

Applying Snell's law at the face AB, we get

$$\mu = \frac{\sin i}{\sin r_1}$$

Substituting the given values, we get

$$\sqrt{2} = \frac{\sin i}{\sin 30°}$$

$$\Rightarrow \sin i = \sin 30° \times \sqrt{2}$$

$$= \frac{1}{2} \times \left(\sqrt{2} \sin 30° = \frac{1}{2}\right)$$

$$= \frac{1}{\sqrt{2}}$$

or $i = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right)$

$= 45° \qquad \left(\because \sin 45° = \frac{1}{\sqrt{2}}\right)$

The angle of incidence of the ray on the prism is 45°.

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16 A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. The refracting angle of second prism should be **[NEET 2017]**

(a) 4° (b) 6° (c) 8° (d) 10°

Ans. *(b)*

Thinking Process For dispersion without deviation, net deviation produced by the combination of prisms must be zero.

Let, prism angle of the first and second prisms are A_1 and A_2 respectively. Similarly, their refractive indices are μ_1 and μ_2.

Condition for dispersion without deviation is

$$\delta_1 - \delta_2 = 0$$

$$\Rightarrow (\mu_1 - 1)A_1 - (\mu_2 - 1)A_2 = 0$$

$$\Rightarrow A_2 = \left(\frac{\mu_1 - 1}{\mu_2 - 1}\right)$$

$$A_1 = \left(\frac{1.42 - 1}{1.7 - 1}\right)(10°) \Rightarrow A_2 = 6°$$

17 The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If the ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are **[NEET 2016]**

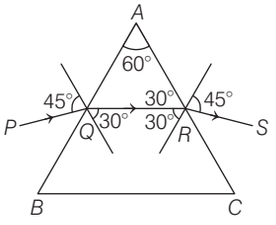
(a) 30°; $\sqrt{2}$ (b) 45°; $\sqrt{2}$

(c) 30°; $\frac{1}{\sqrt{2}}$ (d) 45°; $\frac{1}{\sqrt{2}}$

Ans. *(a)*

Consider a ray of light *PQ* incident an the surface *AB* and moves along *RS*, after passing through the prism *ABC*.

It is given that the incident ray suffers minimum deviation. Therefore, the ray inside the prism must be parallel to the base *BC* of the prism.



From the geometry of the prism and the ray diagram, it is clear that

angle of incidence, $i = 45°$

angle of refraction $r = r' = 30°$

angle of emergence, $e = 45°$

Therefore, minimum deviation suffered by the ray is

$$\delta_{min} = i + e - (r + r')$$

$$= 90° - 60° = 30°$$

Also we know that

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}$$

where, μ = refractive index of the material of the prism.

A = angle of prism = 60°

$$\therefore \quad \mu = \frac{\sin\left(\frac{60° + 30°}{2}\right)}{\sin\frac{60°}{2}} = \frac{\sin 45°}{\sin 30°}$$

$$= \frac{1/\sqrt{2}}{1/2} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

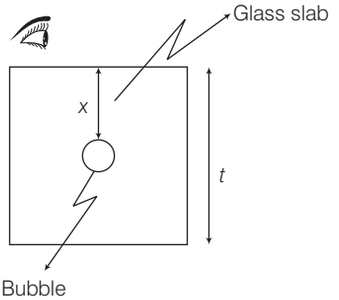
18 An air bubble in a glass slab with refractive index 1.5 (near normal incidence) is 5 cm deep when viewed from one surface and 3 cm deep when viewed from the opposite face. The thickness (in cm) of the slab is **[NEET 2016]**

(a) 8 (b) 10

(c) 12 (d) 16

Ans. *(c)*

Let thickness of the given slab is t. According to the question, when viewed from both the surfaces



$$\frac{x}{\mu} + \frac{t - x}{\mu} = 3 + 5$$

$$\Rightarrow \quad \frac{t}{\mu} = 8\,\text{cm}$$

$$\Rightarrow \quad t = 8 \times \mu$$

$$\Rightarrow \quad t = 8 \times \frac{3}{2} = 12\,\text{cm}$$

19 The refracting angle of a prism is A, and refractive index of the material of the prism is cot $(A/2)$. The angle of minimum deviation is **[CBSE AIPMT 2015]**

(a) 180° – 3A (b) 180° – 2A

(c) 90° – A (d) 180° + 2A

Ans. *(b)*

As, we know that $\mu = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$

$$\Rightarrow \quad \cot\frac{A}{2} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$$

$$\Rightarrow \quad \frac{\cos\frac{A}{2}}{\sin\frac{A}{2}} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin\frac{A}{2}}$$

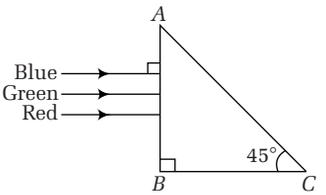
$$\sin\left(\frac{\pi}{2} - \frac{A}{2}\right) = \sin\left(\frac{A + D_m}{2}\right)$$

$$\Rightarrow \quad \frac{\pi}{2} - \frac{A}{2} = \frac{A}{2} + \frac{D_m}{2}$$

$$\Rightarrow \quad D_m = \pi - 2A$$

$$D_m = 180° - 2A$$

20 A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47, respectively. **[CBSE AIPMT 2015]**



The prism will

(a) separate the blue colour part from the red and green colours

(b) separate all the three colours from one another

(c) not separate the three colours at all

(d) separate the red colour part from the green and blue colours

Ans. *(d)*

For refractive index of a index,

$$\mu = \frac{1}{\sin i_c} = \frac{1}{\sin 45°} = \sqrt{2}$$

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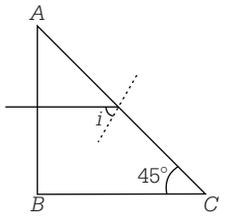


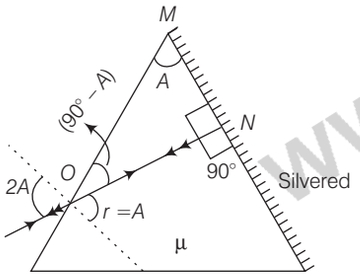
As, $\mu_{red} = 1.39, \mu_{green} = 1.44$
and $\mu_{blue} = 1.47$
$\therefore$
$(\mu_{red} = 1.39) < \mu, \mu_{green} > \mu, \mu_{blue} > \mu$
Thus, only red colour do not suffer total internal reflection.

21 The angle of a prism is A. One of its refracting surfaces is silvered. Light rays falling at an angle of incidence $2A$ on the first surface returns back through the same path after suffering reflection at the silvered surface. The refractive index μ, of the prism is **[CBSE AIPMT 2014]**

(a) $2\sin A$ (b) $2\cos A$
(c) $\frac{1}{2}\cos A$ (d) $\tan A$

Ans. *(b)*

According to question, diagram is shown below.



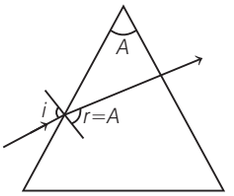
So, $\angle MON = 90° - A$
and $\angle r = 90° - (90° - A)$
$\Rightarrow \angle r = A$
By Snell's law, $\frac{\sin i}{\sin r} = \mu$
$\frac{\sin(2A)}{\sin(A)} = \mu$
$\frac{2\sin A\cos A}{\sin A} = \mu$
$\Rightarrow \mu = 2\cos A$

22 A ray of light is incident at an angle of incidence, i, on one face of a prism of angle A (assumed to be small) and emerges normally from the opposite face. If the refractive index of the prism is μ, the angle of incidence i, is nearly equal to **[CBSE AIPMT 2012]**

(a) μA (b) $\frac{\mu A}{2}$
(c) A/μ (d) $A/2\mu$

Ans. *(a)*

Refractive index
$\mu = \frac{\sin i}{\sin r}, \mu = \frac{\sin i}{\sin A}$
In case of small angle, $\sin i \approx i$ and $\sin A \approx A$



$\mu = \frac{i}{A}$
$i = \mu A$

23 Which of the following is not due to total internal reflection? **[CBSE AIPMT 2011]**

(a) Difference between apparent and real depth of a pond
(b) Mirage on hot summer days
(c) Brilliance of diamond
(d) Working of optical fibre

Ans. *(a)*

Real and apparent depth are explained on the basis of refraction only. The concept of TIR is not involved here.

24 A ray of light travelling in a transparent medium of refractive index μ falls, on a surface separating the medium from air at an angle of incidence of 45°. For which of the following value of μ the ray can undergo total internal reflection? **[CBSE AIPMT 2010]**

(a) $\mu = 1.33$ (b) $\mu = 1.40$
(c) $\mu = 1.50$ (d) $\mu = 1.25$

Ans. *(c)*

For total internal reflection, $i > c$ (initial angle)

So, $\sin i > \sin c$
$\Rightarrow \sin 45° > \frac{1}{\mu}$
$\Rightarrow \mu > \sqrt{2}$
$\Rightarrow \mu > 1.4$

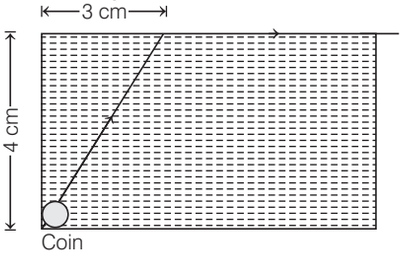
25 The frequency of a light wave in a material is 2×10^{14} Hz and wavelength is 5000 Å. The refractive index of material will be **[CBSE AIPMT 2007]**

(a) 1.40 (b) 1.50 (c) 3.00 (d) 1.33

Ans. *(c)*

Velocity of light waves in material is
$v = \nu\lambda$ ...(i)
Refractive index of material is
$\mu = \frac{c}{v}$ ...(ii)
where, c is speed of light in vacuum or air.
or $\mu = \frac{c}{\nu\lambda}$ ...(iii)
Given, $\nu = 2 \times 10^{14}$ Hz
$\lambda = 5000$ Å $= 5000 \times 10^{-10}$ m,
and $c = 3 \times 10^8$ m/s
Hence, from Eq. (iii), we get
$\mu = \frac{3 \times 10^8}{2 \times 10^{14} \times 5000 \times 10^{-10}} = 3.00$

26 A small coin is resting on the bottom of a beaker filled with a liquid. A ray of light from the coin travels upto the surface of the liquid and moves along its surface (see figure).

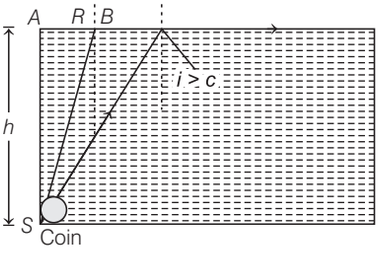


How fast is the light travelling in the liquid? **[CBSE AIPMT 2007]**

(a) 1.8×10^8 m/s (b) 2.4×10^8 m/s
(c) 3.0×10^8 m/s (d) 1.2×10^4 m/s

Ans. *(a)*

As shown in figure, a light ray from the coin will not emerge out of liquid, if $i > C$.



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Therefore, minimum radius R corresponds to $i = C$. In ΔSAB,

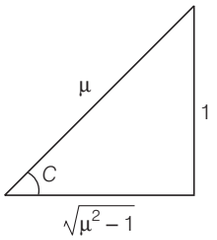
$$\frac{R}{h} = \tan C$$

or $$R = h \tan C$$

or $$R = \frac{h}{\sqrt{\mu^2 - 1}}$$

Given, $R = 3\,\text{cm}, h = 4\,\text{cm}$

Hence, $$\frac{3}{4} = \frac{1}{\sqrt{\mu^2 - 1}}$$



or $$\mu^2 = \frac{25}{9} \text{ or } \mu = \frac{5}{3}$$

But $$\mu = \frac{c}{v} \text{ or } v = \frac{c}{\mu}$$

$$= \frac{3 \times 10^8}{5/3}$$

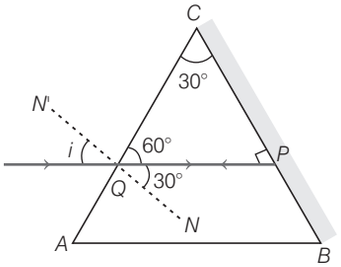
$$= 1.8 \times 10^8 \text{ m/s}$$

27 The refractive index of the material of a prism is $\sqrt{2}$ and its refracting angle is 30°. One of the refracting surfaces of the prism is made a mirror inwards. A beam of monochromatic light entering the prism from the other face will retrace its path after reflection from the mirrored surface, if its angle of incidence on the prism is **[CBSE AIPMT 2004]**

(a) 45° (b) 60°
(c) 0° (d) 30°

Ans. *(a)*

According to the given condition, the beam of light will retrace its path after reflection from BC.



So, $\angle CPQ = 90°$

Thus, angle of refraction at surface AC

$\angle PQN = \angle r = 90° - 60° = 30°$

By Snell's law

$$\mu = \frac{\sin i}{\sin r} \Rightarrow \sqrt{2} = \frac{\sin i}{\sin 30°}$$

$\therefore \sqrt{2} \times \sin 30° = \sin i$

$\Rightarrow \sqrt{2} \times \frac{1}{2} = \sin i$

$\Rightarrow \sin i = \frac{1}{\sqrt{2}} = \sin 45°$

$\therefore i = 45°$

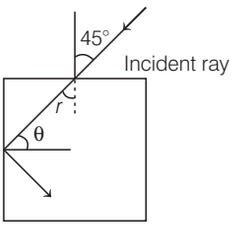
28 A beam of light composed of red and green rays is incident obliquely at a point on the face of a rectangular glass slab. When coming out on the opposite parallel face, the red and green rays emerge from **[CBSE AIPMT 2004]**

(a) two points propagating in two different non-parallel directions
(b) two points propagating in two different parallel directions
(c) one point propagating in two different directions
(d) one point propagating in the same direction

Ans. *(b)*

In any medium other than air or vacuum, the velocities of different colours are different. Therefore, both red and green colours are refracted at different angles of refraction. Hence, after emerging from glass slab through opposite parallel face, they appear at two different points and move in the two different parallel directions.

29 For the given incident ray as shown in figure, the condition of total internal reflection of the ray will be satisfied if the refractive index of block will be **[CBSE AIPMT 2002]**



(a) $\frac{\sqrt{3}+1}{2}$ (b) $\frac{\sqrt{2}+1}{2}$
(c) $\sqrt{\frac{3}{2}}$ (d) $\sqrt{\frac{7}{6}}$

Ans. *(c)*

For total internal reflection to take place,

angle of incidence > critical angle

i.e. $\theta > C$

or $\sin\theta > \sin C$

But for the case of total internal reflection,

$$\sin C = \frac{1}{\mu}$$

and according to question

$$\theta = 90° - r$$

So, $\sin(90° - r) > \frac{1}{\mu}$

i.e. $$\mu > \frac{1}{\cos r}$$

$[\because \sin(90 - r) = \cos r]$...(i)

From Snell's law,

$$\frac{\sin 45°}{\sin r} = \mu \Rightarrow \sin r = \frac{1}{\sqrt{2}\mu}$$

$\therefore \cos r = \sqrt{1 - \sin^2 r} = \sqrt{1 - \frac{1}{2\mu^2}}$

Thus, Eq. (i) becomes

$$\mu > \frac{1}{\sqrt{1 - \frac{1}{2\mu^2}}}$$

$\therefore$ $$\mu^2 = \frac{1}{1 - \frac{1}{2\mu^2}}$$

or $$\mu^2 - \frac{1}{2} = 1 \text{ or } \mu = \sqrt{\frac{3}{2}}$$

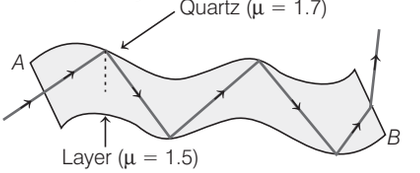
30 Transmission of light in optical fibre is due to **[CBSE AIPMT 2001]**

(a) scattering
(b) diffraction
(c) polarisation
(d) multiple total internal reflections

Ans. *(d)*

An optical fibre is a device based on total internal reflection by which a light signal can be transferred from one place to the other with a negligible loss of energy.

It consists of a very long and thin fibre of quartz glass.



When a light ray is incident at one end A of fibre making a small angle of incidence. It suffers multiple total internal reflections and finally it reaches the point B.

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31 A transparent cube contains a small air bubble. Its apparent distance is 2 cm when seen through one face and 5 cm when seen through other face. If the refractive index of the material of the cube is 1.5, the real length of the edge of cube must be **[CBSE AIPMT 2000]**

(a) 7 cm (b) 7.5 cm
(c) 10.5 cm (d) $\frac{14}{3}$ cm

Ans. *(c)*

As light travels from denser to rarer medium, so

refractive index $(\mu) = \frac{\text{real depth}}{\text{apparent depth}}$

Refractive index $(\mu) = 1.5$
Net apparent depth $= 2 + 5 = 7$ cm
And real depth = apparent depth $\times \mu$
$\therefore$ Real depth $= 1.5 \times 7 = 10.5$ cm

32 Rainbows are formed by **[CBSE AIPMT 2000]**

(a) reflection and diffraction
(b) refraction and scattering
(c) dispersion and total internal reflection
(d) interference only

Ans. *(c)*

When white light from sun falls on raindrops, sometimes a band of different colours in form of a circular arc is seen in the sky. This is called the rainbow.

The reason of origin of rainbow is that the small drops of water behave like a prism for the white sunlight due to which refraction, dispersion and total internal reflection of white light occurs from the water drops.

The rainbow is not seen after every rain, but is seen only when the light rays of particular colour suffer minimum deviation after one or two total internal reflections inside the small water drops.

33 The refractive index of the material of the prism is $\sqrt{3}$, then the angle of minimum deviation of the prism is **[CBSE AIPMT 1999]**

(a) 30° (b) 45° (c) 60° (d) 75°

Ans. *(c)*

The refractive index of material of prism (from Snell's law) is

$$\mu = \frac{\sin i}{\sin r}$$

Here, $i = \frac{A + \delta_m}{2}$ and $r = \frac{A}{2}$

where, A is the angle of prism and δ_m the angle of minimum deviation.

In case of minimum deviation, refractive index of prism is given by

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}$$

Given, $\mu = \sqrt{3}$, $A = 60°$ (for prism)

Thus, $\sqrt{3} = \frac{\sin\left(\frac{60 + \delta_m}{2}\right)}{\sin 30°}$

or $\sin\left(\frac{60 + \delta_m}{2}\right) = \frac{1}{2} \times \sqrt{3}$

or $\sin\left(\frac{60 + \delta_m}{2}\right) = \sin 60°$

or $\frac{60 + \delta_m}{2} = 60$

or $\delta_m = 2 \times 60 - 60 = 60°$

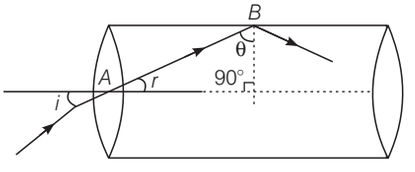
34 Light enters at an angle of incidence in a transparent rod of refractive index μ. For what value of the refractive index of the material of the rod the light once entered into it will not leave it through its lateral face whatsoever be the value of angle of incidence ? **[CBSE AIPMT 1998]**

(a) $\mu > \sqrt{2}$ (b) $\mu = 1$
(c) $\mu = 1.1$ (d) $\mu = 1.3$

Ans. *(a)*

Suppose a light ray enters at A and refracted beam is AB. At the lateral face, the angle of incidence is θ. For no refraction at this face, $\theta > C$

$$\sin\theta > \sin C$$



but $\theta + r = 90°$

(According to geometry of figure)

$\Rightarrow \quad \theta = (90° - r)$

$\therefore \quad \sin(90° - r) > \sin C$

or $\cos r > \sin C$ ...(i)

Now from Snell's law,

$$\mu = \frac{\sin i}{\sin r} \Rightarrow \sin r = \frac{\sin i}{\mu}$$

As from trigonometry,

$$\cos r = \sqrt{1 - \sin^2 r}$$

$\therefore \quad \cos r = \sqrt{\left(1 - \frac{\sin^2 i}{\mu^2}\right)}$

$\therefore$ Eq. (i) gives,

$$\sqrt{1 - \frac{\sin^2 i}{\mu^2}} > \sin C$$

$\Rightarrow \quad 1 - \frac{\sin^2 i}{\mu^2} > \sin^2 C$

Also $\sin C = \frac{1}{\mu}$

$\therefore \quad 1 - \frac{\sin^2 i}{\mu^2} > \frac{1}{\mu^2}$

or $1 > \frac{1}{\mu^2} + \frac{\sin^2 i}{\mu^2}$

or $\frac{1}{\mu^2}(\sin^2 i + 1) < 1$

or $\mu^2 > \sin^2 i + 1$

The maximum value of $\sin i$ is 1. So,

$\therefore \quad \mu^2 > 2$ or $\mu > \sqrt{2}$

35 Electromagnetic radiation of frequency ν, velocity v and wavelength λ, in air, enters a glass slab of refractive index μ. The frequency, wavelength and velocity of light in the glass slab will be, respectively **[CBSE AIPMT 1997]**

(a) $\frac{\nu}{\mu}, \frac{\lambda}{\mu}, v$ (b) $\nu, \lambda, \frac{v}{\mu}$
(c) $\nu, \frac{\lambda}{\mu}, \frac{v}{\mu}$ (d) $\frac{\nu}{\mu}, \frac{\lambda}{\mu}, \frac{v}{\mu}$

Ans. *(c)*

When electromagnetic wave enters in other medium, frequency remains unchanged while wavelength and velocity become $\frac{1}{\mu}$ times.

So, after entering from air to glass slab of refractive index (μ), frequency remains ν, wavelength $\lambda' = \frac{\lambda}{\mu}$ and velocity of light $v' = \frac{v}{\mu}$.

36 If f_V and f_R are the focal lengths of a convex lens for violet and red light respectively and F_V and F_R are the focal lengths of concave lens for violet and red light respectively, then we have **[CBSE AIPMT 1996]**

(a) $f_V < f_R$ and $F_V > F_R$
(b) $f_V < f_R$ and $F_V < F_R$
(c) $f_V > f_R$ and $F_V > F_R$
(d) $f_V > f_R$ and $F_V < F_R$

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Ans. *(a)*

According to Cauchy relation,

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots \Rightarrow \mu \propto \frac{1}{\lambda}$$

Hence, focal length $f \propto \lambda$

For a convex lens, $f_R > f_V$ or $f_V < f_R$.

For a concave lens, focal length is negative.

So, focal length of concave lens for violet light

F_V > Focal length of concave lens for red light F_R.

37 One face of a rectangular glass plate 6 cm thick is silvered. An object held 8 cm in front of the first face, forms an image 12 cm behind the silvered face. The refractive index of the glass is **[CBSE AIPMT 1996]**

(a) 0.4 (b) 0.8 (c) 1.2 (d) 1.6

Ans. *(c)*

Given,

Thickness of rectangular glass plate $(t) = 6$ cm

Distance of the object $(u) = 8$ cm

Distance of the image $(v) = 12$ cm

Let y = apparent position of the silvered surface.

From property of mirror,

Image distance of object from the mirror

= distance of image from the mirror

i.e. $y + 8 = 12 + 6 - y$

$\therefore \quad y = 5$ cm

$\therefore \quad \mu = \dfrac{\text{real depth}}{\text{apparent depth}} = \dfrac{6}{5} = 1.2$

38 Light travels through a glass plate of thickness t and refractive index μ. If c is the speed of light in vacuum, the time taken by light to travel this thickness of glass is **[CBSE AIPMT 1996]**

(a) μtc (b) $\dfrac{tc}{\mu}$

(c) $\dfrac{1}{\mu t}$ (d) $\dfrac{\mu t}{c}$

Ans. *(d)*

Here, total thickness $= t$

Refractive index $= \mu$

Speed of light in glass plate $= \dfrac{c}{\mu}$

$$\left[\because v = \frac{\text{speed of light in vacuum}}{\text{refractive index of medium}}\right]$$

$\therefore$ Time taken by light to travel this thickness of glass

$$= \frac{t}{\left(\frac{c}{\mu}\right)} = \frac{\mu t}{c}$$

39. An achromatic combination of lenses is formed by joining **[CBSE AIPMT 1995]**

(a) 2 convex lenses

(b) 2 concave lenses

(c) 1 convex, 1 concave lens

(d) 1 convex and 1 plane mirror

Ans. *(c)*

When two or more lenses are combined together in such a way that the combination is free from chromatic aberration, then such a combination is called achromatic combination of lenses. For this purpose, one lens should be convex and other a concave lens.

40 Angle of deviation (δ) by a prism (refractive index $= \mu$, and supposing the angle of prism A to be small) can be given by **[CBSE AIPMT 1994]**

(a) $\delta = (\mu - 1)A$ (b) $\delta = (\mu + 1)A$

(c) $\delta = \dfrac{\sin\frac{A+\delta}{2}}{\sin\frac{A}{2}}$ (d) $\delta = \dfrac{\mu - 1}{\mu + 1}A$

Ans. *(a)*

When refracting angle of a prism is small $(\angle 10°)$, the deviation δ is calculated from the relation $\delta = (\mu - 1)A$. For prisms with bigger refracting angles, we use the relation

$$\delta = (i_1 + i_2) - A$$

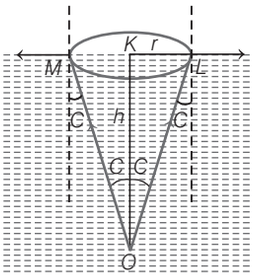
41 A point source of light is placed 4 m below the surface of water of refractive index $\dfrac{5}{3}$. The minimum diameter of a disc, which should be placed over the source, on the surface of water to cut off all light coming out of water is **[CBSE AIPMT 1994]**

(a) infinite (b) 6 m

(c) 4 m (d) 3 m

Ans. *(b)*

In figure, O is the point source of light, K is centre of disc of radius r, $OK = h$. The source will not be seen at all when the height is such that $\angle KOL = C$. (i.e. critical angle between water and air.)



From figure,

$$\sin C = \frac{KL}{OL} = \frac{r}{\sqrt{r^2 + h^2}}$$

For total internal reflection of light,

$$\sin C = \frac{1}{\mu} = \frac{r}{\sqrt{r^2 + h^2}}$$

$\therefore \quad r^2 + h^2 = \mu^2 r^2$

or $\quad h^2 = r^2(\mu^2 - 1)$

Given, $\quad h = 4$ m, $\mu = \dfrac{5}{3}$

or $\quad r^2 = \dfrac{h^2}{\mu^2 - 1} = \dfrac{(4)^2}{\left(\frac{5}{3}\right)^2 - 1}$

So, $\quad r^2 = 9$

$\therefore \quad r = 3$ m

$\therefore$ Diameter of disc $= 2r = 6$ m

42 Time taken by sunlight to pass through a window of thickness 4 mm whose refractive index is $\dfrac{3}{2}$, is **[CBSE AIPMT 1993]**

(a) 2×10^{-4} s (b) 2×10^{8} s

(c) 2×10^{-11} s (d) 2×10^{11} s

Ans. *(c)*

Let x be thickness of window, v be velocity of light entering in window, so time taken by sunlight to pass through the window.

$$t = \frac{x}{v} = \frac{x}{\frac{c}{\mu}} = \frac{\mu x}{c} \qquad \left[v = \frac{c}{\mu}\right]$$

$\therefore \quad t = \dfrac{1.5 \times 4 \times 10^{-3}}{3 \times 10^8} = 2 \times 10^{-11}$ s

43 There is a prism with refractive index equal to $\sqrt{2}$ and the refracting angle equal to 30°. One of the refracting surface of the prism is polished. A beam of monochromatic will retrace its path if its angle of incidence over the refracting surface of the prism is **[CBSE AIPMT 1992]**

(a) 0° (b) 30°

(c) 45° (d) 60°

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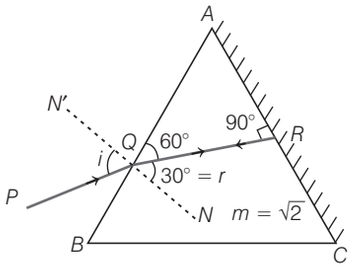
Ans. *(c)*

The ray *QR* will retrace its path, when



$\angle ARQ = 90°, \quad \angle r = 30°$

$\therefore \quad \angle AQR = 90° - 30° = 60°$

As from Snell's law,

$\sin i \times 1 = \sin r \times \mu$

$\sin i = \mu \sin r = \sqrt{2} \sin 30°$

[Refractive index of air = 1]

$= \sqrt{2} \times \frac{1}{2} = \frac{1}{\sqrt{2}}$

$\therefore \quad \angle i = 45°$

44 A beam of monochromatic light is refracted from vacuum into a medium of refractive index 1.5. The wavelength of refracted light will be **[CBSE AIPMT 1991, 1992]**

(a) dependent on intensity of refracted light
(b) same
(c) smaller
(d) larger

Ans. *(c)*

Refractive index,

$$\mu = \frac{c}{v} = \frac{\nu\lambda_v}{\nu\lambda_m}$$

As,

c = velocity of light in vacuum

v = velocity of light in medium

$v = \nu\lambda$ and ν remains constant during refraction

$\therefore \quad \lambda_m = \frac{\lambda_v}{\mu}$

$\Rightarrow \quad \lambda_m < \lambda_v \quad (\because \mu = 1, \text{ given})$

Hence, the wavelength decreases in second medium.

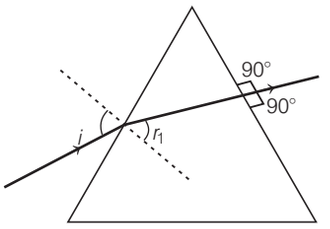
45 A ray is incident at an angle of incidence i on one surface of a prism of small angle A and emerge normally from opposite surface. If the refractive index of the material of prism is μ, the angle of incidence i is nearly equal to **[CBSE AIPMT 1989]**

(a) $\frac{A}{\mu}$ (b) $\frac{A}{2\mu}$ (c) μA (d) $\frac{\mu A}{2}$

Ans. *(c)*

Angle of prism is given by $A = r_1 + r_2$

where, r_1 is refraction angle on incident face and r_2 is angle of incidence on 2nd face of prism. As refracted ray emerges normally from opposite surface, $r_2 = 0$.



$\therefore \quad A = r_1$

Now, $\mu = \frac{\sin i}{\sin r_1}$

If $\angle i_1$ and $\angle r_1$ are very small then, $\sin i \approx i, \sin r_1 \approx r_1$

$\therefore \quad \mu = \frac{i}{r_1} = \frac{i}{A}$

$\therefore \quad i = \mu A$

TOPIC 3
Lenses

46. A convex lens A of focal length 20 cm and a concave lens B of focal length 5 cm are kept along the same axis with a distance d between them. If a parallel beam of light falling on A leaves B as a parallel beam, then the distance d (in cm) will be **[NEET 2021]**

(a) 25 (b) 15 (c) 50 (d) 30

Ans. *(b)*

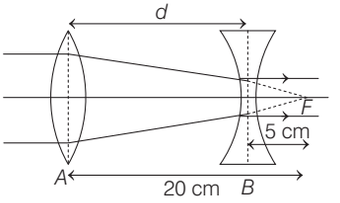
Given, the focal length of convex lens A,

$$f_1 = +20 \text{ cm}$$

The focal length of concave lens B,

$$f_2 = -5 \text{ cm}$$

The convex lens is the converging lens and the concave lens is the diverging lens.



When the parallel beam of light passes through the convex lens, it converges at the focal point F and the distance between lens A to F point is 20 cm.

Now, after emerging from the lens B, the beam is still parallel in nature. So, the net focal length of the lens A and B will be infinite.

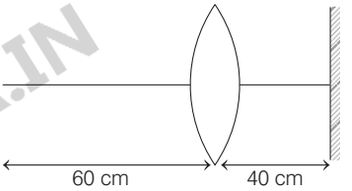
As we know,

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f} - \frac{d}{f_1 f_2}$$

$$\Rightarrow \quad \frac{1}{\infty} = \frac{1}{20} - \frac{1}{5} + \frac{d}{20 \times 5}$$

$$\Rightarrow \quad \frac{3}{20} = \frac{d}{20 \times 5} \quad \text{or} \quad d = 3 \times 5 = 15 \text{ cm}$$

47 A point object is placed at a distance of 60 cm from a convex lens of focal length 30 cm. If a plane mirror were put perpendicular to the principal axis of the lens and at a distance of 40 cm from it, the final image would be formed at a distance of **[NEET 2021]**



(a) 20 cm from the lens, it would be a real image
(b) 30 cm from the lens, it would be a real image
(c) 30 cm from the plane mirror, it would be a virtual image
(d) 20 cm from the plane mirror, it would be a virtual image

Ans. *(d)*

Given, the focal length of the convex lens,

$$f = +30 \text{ cm}$$

The object distance from the lens,

$$u = -60 \text{ cm}$$

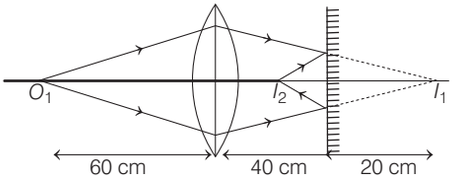
The image formed by the lens be at distance v, then by using lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{1}{+30} = \frac{1}{v} - \frac{1}{(-60)} \quad \Rightarrow \quad \frac{1}{+30} = \frac{60 + v}{60v}$$

$$\Rightarrow \quad 2v = 60 + v \quad \Rightarrow \quad v = 60 \text{ cm}$$

Let's draw the ray diagram of the convex lens and mirror.



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This real image will now act as a virtual object for the mirror.

Thus, a real image from the mirror is formed 20 cm in front of the mirror. Hence, at 20 cm distance from the lens. Also, this real image acts as an object for lens for final image.

Again by using lens formula,

$$\frac{1}{v}+\frac{1}{20}=\frac{1}{30}$$

or $v=-60$ cm from the lens

i.e., 20 cm from the plane mirror and virtual in nature.

48 A plano-convex lens of unknown material and unknown focal length is given. With the help of a spherometer we can measure the **[NEET (Oct.) 2020]**

(a) focal length of the lens
(b) radius of curvature of the curved surface
(c) aperture of the lens
(d) refractive index of the material

Ans. *(b)*

Spherometer is used to measure the radius of curvature of an item such as a lens and curved mirrors that are spherical in shape.

49 The power of a biconvex lens is 10 D and the radius of curvature of each surface is 10 cm. Then, the refractive index of the material of the lens is **[NEET (Oct.) 2020]**

(a) $\frac{4}{3}$ (b) $\frac{9}{8}$ (c) $\frac{5}{3}$ (d) $\frac{3}{2}$

Ans. *(d)*

Power of biconvex lens,

$$P=10\text{D}$$

$$\therefore \quad f=\frac{1}{P}=\frac{1}{10}=0.1\,\text{m}=10\ \text{cm}$$

$$R_1=R_2=10\ \text{cm}$$

By lens Maker's formula,

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \quad \frac{1}{10}=(\mu-1)\left(\frac{1}{10}-\frac{1}{-10}\right)$$

$$\Rightarrow \quad \frac{1}{10}=(\mu-1)\left(\frac{2}{10}\right)$$

$$\Rightarrow \quad 1=(\mu-1)\times 2$$

$$\Rightarrow \quad \mu-1=\frac{1}{2}$$

$$\Rightarrow \quad \mu=1+\frac{1}{2}=\frac{3}{2}$$

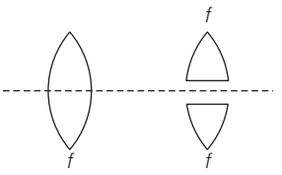
50 An equi-convex lens has power P it is cut into two symmetrical halves by a plane containing the principal axis. The power of one part will be **[NEET (Odisha) 2019]**

(a) 0 (b) $\frac{P}{2}$ (c) $\frac{P}{4}$ (d) P

Ans. *(d)*

When the lens is cut along its principal axis, the focal length of the two halves will remain same because the radius of curvature of both the surfaces are still same. So, the power also remains same as

$$P=\frac{1}{f}$$



51 A double convex lens has focal length 25 cm. The radius of curvature of one of the surfaces is doubled of the other. Find the radii, if the refractive index of the material of the lens is 1.5. **[NEET (Odisha) 2019]**

(a) 100 cm, 50 cm
(b) 25 cm, 50 cm
(c) 18.75 cm, 37.5 cm
(d) 50 cm, 100 cm

Ans. *(c)*

Using the lens maker's formula

$$\frac{1}{f}=\left(\frac{\mu_2-\mu_1}{\mu_1}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Here, $f=25$ cm, $\mu_2=1.5$, $\mu_1=1$(for air)

let $R_1=R$ and $R_2=-2R$

$$\Rightarrow \quad \frac{1}{25}=\left(\frac{1.5-1}{1}\right)\left[\frac{1}{R}-\left(-\frac{1}{2R}\right)\right]$$

$$\frac{1}{25\times 0.5}=\frac{1}{R}+\frac{1}{2R}$$

$$\Rightarrow \quad R=\frac{3}{2}\times 25\times 0.5=18.75\,\text{cm}$$

$$\therefore \quad R_1=18.75\,\text{cm}$$

$$R_2=2\times 18.75=37.5\,\text{cm}$$

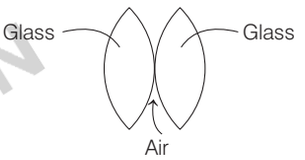
52 Two similar thin equi-convex lenses, of focal length f each, are kept co-axially in contact with each other such that the focal length of the combination is F_1. When the space between the two lenses is filled with glycerine (which has the same refractive index ($\mu=1.5$) as that of glass) then the equivalent focal length is F_2. The ratio $F_1:F_2$ will be **[NEET (National) 2019]**

(a) 1 : 2 (b) 2 : 3
(c) 3 : 4 (d) 2 : 1

Ans. *(a)*

Key Idea When the space between two convex lenses is filled with a liquid of refractive index same as that of glass of lens, then it behaves like a diverging lens, i.e. it forms a bi-concave lens.

Case I When two equi-convex lens of focal length f_1 and f_2 respectively, are kept co-axially in contact, then the equivalent focal length of combination is

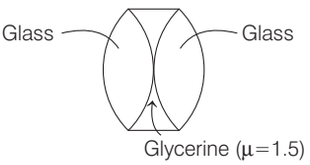


$$\frac{1}{F_1}=\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{f}+\frac{1}{f} \qquad [\because \text{Here, } f_1=f_2]$$

$$=\frac{2}{f}$$

$$\Rightarrow \quad F_1=\frac{f}{2} \qquad \ldots(\text{i})$$

Case II When glycerine of same refractive index at that of the glass is filled in the space between two lens, then the combination will now comprises of three lenses; first bi-convex, second bi-concave and third is bi-convex. So, the focal length of the combination now is given as



$$\frac{1}{F_2}=\frac{1}{f}+\frac{1}{(-f)}+\frac{1}{f}=\frac{1}{f}$$

$$\Rightarrow \quad F_2=f \qquad \ldots(\text{ii})$$

From Eqs. (i) and (ii), we get

$$F_1:F_2=1:2$$

53 Two identical glass ($\mu_g=3/2$) equi-convex lenses of focal length f each are kept in contact. The space between the two lenses is

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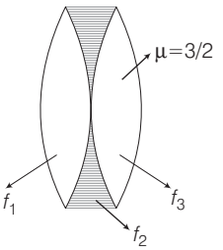
filled with water ($\mu_w = 4/3$). The focal length of the combination is **[NEET 2016]**

(a) $f/3$ (b) f
(c) $\frac{4f}{3}$ (d) $\frac{3f}{4}$

Ans. *(d)*

Consider the situation shown is figure.Let radius of curvature of lens surfaces is R. The combination is equivalent to three lenses in contact.



$$\therefore \frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}$$
$$= \frac{2}{f_1} + \frac{1}{f_2} \quad (\because f_1 = f_3)$$

Now $\frac{1}{f_1} = \frac{1}{f_3} = (\mu - 1)\left(\frac{2}{R}\right) = \frac{1}{f}$

$$\frac{1}{f_2} = (\mu_w - 1)\left(-\frac{2}{R}\right) = \left(\frac{4}{3} - 1\right)\left(\frac{-2}{R}\right)$$
$$= \left(\frac{1}{3}\right)\left(-\frac{2}{R}\right) = \left(\frac{-2}{3}\right)\left(\frac{1}{2(\mu - 1)}\right)$$

$$\Rightarrow \frac{1}{f_2} = \left(-\frac{1}{3}\right)\left(\frac{1}{\frac{3}{2} - 1}\right)\left(\frac{1}{f}\right) = -\frac{2}{3} \times \frac{1}{f}$$

$$\therefore \frac{1}{f_{eq}} = \frac{2}{f} - \frac{2}{3} \times \frac{1}{f}$$
$$= \frac{6-2}{3f} = \frac{4}{3f}$$

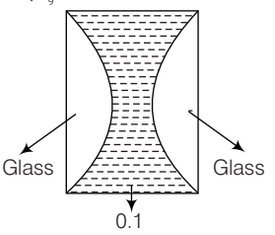
$$\Rightarrow f_{eq} = \frac{3f}{4}$$

54 Two identical thin plano-convex glass lenses (refractive index 1.5) each having radius of curvature of 20 cm are placed with their convex surfaces in contact at the centre. The intervening space is filled with oil of refractive index 1.7. The focal length of the combination is **[CBSE AIPMT 2015]**

(a) – 20 cm
(b) – 25 cm
(c) – 50 cm
(d) 50 cm

Ans. *(c)*

Given $\mu_g = 1.5$



$\mu_{oil} = 1.7 \Rightarrow R = 20$ cm

From Lens Maker's formula for the plano convex lens

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Here, $R_1 = R$

and for plane surface $R_2 = \infty$

$$\therefore \frac{1}{f_{lens}} = (1.5 - 1)\left(\frac{1}{R} - 0\right) \Rightarrow \frac{1}{f_{lens}} = \frac{0.5}{R}$$

When the intervening medium is filled with oil, then focal length of the concave lens formed by the oil

$$\frac{1}{f_{concave}} = (1.7 - 1)\left(-\frac{1}{R} - \frac{1}{R}\right)$$
$$= -0.7 \times \frac{2}{R} = \frac{-1.4}{R}$$

Here, we have two concave surfaces

So, $\frac{1}{f_{eq}} = 2 \times \frac{1}{f} + \frac{1}{f}$

$$= 2 \times \frac{0.5}{R} + \left(\frac{-1.4}{R}\right) = \frac{1}{R} - \frac{1.4}{R} = -\frac{0.4}{R}$$

$$\therefore f_{eq} = -\frac{R}{0.4} = -\frac{20}{0.4} = -50 \text{ cm}$$

55 A plano-convex lens fits exactly into a plano-concave lens. Their plane surfaces are parallel to each other. If lenses are made of different materials of refractive indices μ_1 and μ_2 and R is the radius of curvature of the curved surface of the lenses, then the focal length of the combination is **[NEET 2013]**

(a) $\frac{R}{2(\mu_1 + \mu_2)}$ (b) $\frac{R}{2(\mu_1 - \mu_2)}$
(c) $\frac{R}{(\mu_1 - \mu_2)}$ (d) $\frac{2R}{(\mu_2 - \mu_1)}$

Ans. *(c)*

Focal length of the combination

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \quad \ldots(i)$$

We have $\frac{1}{f_1} = (\mu_1 - 1)\left(\frac{1}{\infty} - \frac{1}{-R}\right) = \frac{\mu_1 - 1}{R}$

and $\frac{1}{f_2} = (\mu_2 - 1)\left(\frac{1}{-R} - \frac{1}{\infty}\right) = -\frac{(\mu_2 - 1)}{R}$

Putting these values of $\frac{1}{f_1}$ and $\frac{1}{f_2}$ in Eq. (i)

$$\frac{1}{f} = \frac{(\mu_1 - 1)}{R} - \frac{(\mu_2 - 1)}{R}$$
$$= \frac{[\mu_1 - 1 - \mu_2 + 1]}{R} = \frac{\mu_1 - \mu_2}{R}$$
$$f = \frac{R}{\mu_1 - \mu_2}$$

56 When a biconvex lens of glass having refractive index 1.47 is dipped in a liquid, it acts as a plane sheet of glass. This implies that the liquid must have refractive index **[CBSE AIPMT 2012]**

(a) equal to that of glass
(b) less than one
(c) greater than that of glass
(d) less than that of glass

Ans. *(a)*

If biconvex lens behaves like a plane sheet of glass, ray will pass undeviated through it only when medium has same refractive index as that of biconvex lens.

57. A biconvex lens has a radius of curvature of magnitude 20 cm. Which one of the following options describe best the image formed of an object of height 2 cm placed 30 cm from the lens? **[CBSE AIPMT 2011]**

(a) Virtual, upright, height = 0.5 cm
(b) Real, inverted, height = 4 cm
(c) Real, inverted, height = 1 cm
(d) Virtual, upright, height = 1 cm

Ans. *(b)*

Given, $R = 20$ cm
$h_0 = 2$ cm and $u = -30$ cm

In general we have assumed $\mu = 1.5$

As $\frac{1}{f} = (1.5 - 1) \times \frac{2}{20} = \frac{1}{20}$

So, $f = 20$ cm

Now, as $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$$\frac{1}{20} = \frac{1}{v} + \frac{1}{30}$$
$$\frac{1}{v} = \frac{1}{20} - \frac{1}{30} = \frac{10}{600}$$

$\therefore v = 60$ cm

As $m = \frac{v}{u} = \frac{60}{-30} = -2$

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$$\Rightarrow \quad m = \frac{h_i}{h_o} = -2$$

$$\therefore \quad h_i = -2 \times 2 = -4\text{cm}$$

Here, image is real, inverted, magnified and height of image is 4 cm.

58 A lens having focal length f and aperture of diameter d forms an image of intensity I. Aperture of diameter $\frac{d}{2}$ in central region of lens is covered by a black paper. Focal length of lens and intensity of image now will be respectively **[CBSE AIPMT 2010]**

(a) f and $\frac{I}{4}$ (b) $\frac{3f}{4}$ and $\frac{I}{2}$

(c) f and $\frac{3I}{4}$ (d) $\frac{f}{2}$ and $\frac{I}{2}$

Ans. *(c)*

As we know that

Intensity, $I \propto A$(Area exposed)

$$\Rightarrow \quad \frac{I_2}{I_1} = \left[\frac{A_2}{A_1}\right]$$

$$= \frac{\frac{\pi d^2}{4} - \frac{\pi d^2/4}{4}}{\frac{\pi d^2}{4}} = \frac{3}{4}$$

$$\Rightarrow \quad I_2 = \frac{3}{4} I_1$$

and focal length remains unchanged.

59 A boy is trying to start a fire by focusing sunlight on a piece of paper using an equiconvex lens of focal length 10 cm. The diameter of the sun is $\mathbf{1.39 \times 10^9}$ m and its mean distance from the earth is $\mathbf{1.5 \times 10^{11}}$ **m.** What is the diameter of the sun's image on the paper ? **[CBSE AIPMT 2008]**

(a) 9.2×10^{-4} m (b) 6.5×10^{-4} m

(c) 6.5×10^{-5} m (d) 12.4×10^{-4} m

Ans. *(a)*

The diameter of the sun, $O = 1.39 \times 10^9$ m and its image is I. As the distance of sun from lens $u = 1.5 \times 10^{11}$ m and from paper is $v = 0.1$ m.

Then by using relation

$$\frac{I}{O} = \frac{v}{u}$$

$$\Rightarrow \quad \frac{I}{1.39 \times 10^9} = \frac{0.1}{1.5 \times 10^{11}}$$

we get $I = 9.2 \times 10^{-4}$ m

60 Two thin lenses of focal lengths f_1 and f_2 are in contact and coaxial. The power of the combination is **[CBSE AIPMT 2008]**

(a) $\sqrt{\frac{f_1}{f_2}}$ (b) $\sqrt{\frac{f_2}{f_1}}$

(c) $\frac{f_1 + f_2}{2}$ (d) $\frac{f_1 + f_2}{f_1 f_2}$

Ans. *(d)*

As and we know that $P_{eq} = P_1 + P_2$

$$\frac{1}{F_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\therefore \quad F_{eq} = \frac{f_1 f_2}{f_1 + f_2}$$

As $P = \frac{1}{F}$

$$\therefore \quad P_{eq} = \frac{f_1 + f_2}{f_1 f_2}$$

61 A convex lens and a concave lens, each having same focal length of 25 cm, are put in contact to form a combination of lenses. The power in diopters of the combination is **[CBSE AIPMT 2006]**

(a) 25 (b) 50

(c) infinite (d) zero

Ans. *(d)*

Focal length of combination of lenses placed in contact is

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

For convex lens $f_1 = 25\,\text{cm}$

For concave lens, $f_2 = -25\,\text{cm}$

Hence, $\frac{1}{F} = \frac{1}{25} + \frac{1}{-25} = \frac{1}{25} - \frac{1}{25} = 0$

$$\therefore \quad F = \frac{1}{0} = \infty$$

Hence, power of combination,

$$P = \frac{1}{F} = 0\,\text{D}$$

62 A convex lens is dipped in a liquid whose refractive index is equal to the refractive index of the lens. Then its focal length will **[CBSE AIPMT 2003]**

(a) become small, but non-zero

(b) remain unchanged

(c) become zero

(d) become infinite

Ans. *(d)*

From lens maker's formula

$$\frac{1}{f} = (\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(i)$$

When convex lens is dipped in a liquid of refractive index (μ_l), then its focal length becomes

$$\frac{1}{f_l} = \left(\frac{\mu_g}{\mu_l} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

or $\frac{1}{f_l} = \frac{(\mu_g - \mu_l)}{\mu_l}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ...(ii)

Dividing Eq. (i) by Eq. (ii), we get

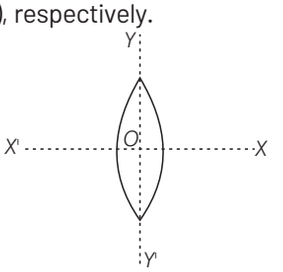
$$\frac{f_l}{f} = \frac{(\mu_g - 1)\mu_l}{(\mu_g - \mu_l)} \quad \ldots(iii)$$

But it is given that refractive index of lens is equal to refractive index of liquid i.e. $\mu_g = \mu_l$.

Hence, Eq. (iii) gives,

$$\frac{f_l}{f} = \frac{(\mu_g - 1)\mu_l}{0} = \infty \quad \text{(infinity)}$$

63 An equiconvex lens is cut into two halves along (i) XOX' and (ii) YOY' as shown in the figure. Let f, f', f'' be the focal lengths of the complete lens, of each half in case (i), and of each half in case (ii), respectively.



Choose the correct statement from the following **[CBSE AIPMT 2003]**

(a) $f' = f, f'' = f$ (b) $f' = 2f, f'' = 2f$

(c) $f' = f, f'' = 2f$ (d) $f' = 2f, f'' = f$

Ans. *(c)*

Initially, the focal length of equiconvex lens is

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots(i)$$

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{-R}\right) = \frac{2(\mu - 1)}{R}$$

Case I When lens is cut along XOX', then each half is again equiconvex with

$R_1 = R, \; R_2 = -R$

Thus, $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R} - \frac{1}{(-R)}\right]$

$$= (\mu - 1)\left[\frac{1}{R} + \frac{1}{R}\right]$$

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$$= (\mu - 1)\frac{2}{R} = \frac{1}{f'}$$

$\Rightarrow \quad f' = f$

Case **II** When lens is cut along YOY′, then each half becomes planoconvex with

$R_1 = R, \quad R_2 = \infty$

Thus, $\frac{1}{f''} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

$= (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right)$

$= \frac{(\mu - 1)}{R} = \frac{1}{2f}$

Hence, $f' = f, \quad f'' = 2f$

Note When we cut a convex lens along principal axis both the lens formed are convex lens of same focal length as that of original.

When we cut a convex lens vertical to principal axis, each lens has focal length twice of original.

64 A body is located on a wall. Its image of equal size is to be obtained on a parallel wall with the help of a convex lens. The lens is placed at a distance d ahead of second wall, then the required focal length will be **[CBSE AIPMT 2002]**

(a) only $\frac{d}{4}$

(b) only $\frac{d}{2}$

(c) more than $\frac{d}{4}$ but less than $\frac{d}{2}$

(d) less than $\frac{d}{4}$

Ans. *(b)*

Concept For equal size of image and object, object must be placed of centre of curvature of lens i.e. $u = v$.

The lens formula can be written as

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \qquad ...(i)$$

Given, $v = d$

For equal sized image,

$|v| = |u| = d$

By sign convention,

$u = -d$

$\therefore \quad \frac{1}{f} = \frac{1}{d} + \frac{1}{d}$ or $f = \frac{d}{2}$

65 A planoconvex lens is made of a material of refractive index $\mu = 1.5$. The radius of curvature of curved surface of the lens is 20 cm. If its plane surface is silvered, the focal length of the silvered lens will be **[CBSE AIPMT 2000]**

(a) 10 cm (b) 20 cm
(c) 40 cm (d) 80 cm

Ans. *(b)*

When a ray falls on convex surface of a planoconvex lens, then it is first refracted and reflected from plane surface and then finally refracted from convex surface. Thus, two refractions and one reflection take place.

Since, refraction takes place two times and reflection takes place one time

So, focal length of planoconvex lens is

$$\frac{1}{F} = \frac{2}{f_l} + \frac{1}{f_m} \qquad ...(i)$$

If plane surface is silvered, so

$$f_m = \frac{R_2}{2} = \frac{\infty}{2} = \infty$$

And from lens maker formula

$$\frac{1}{f_l} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{(\mu - 1)}{R}$$

$\therefore \quad \frac{1}{F} = \frac{2(\mu - 1)}{R} + \frac{1}{\infty}$

$$= \frac{2(\mu - 1)}{R}$$

or $F = \frac{R}{2(\mu - 1)} \qquad ...(ii)$

Given, $R = 20$ cm, $\mu = 1.5$

Hence, $F = \frac{20}{2(1.5 - 1)} = \frac{20}{2 \times 0.5}$

$= 20$ cm

66 A planoconvex lens is made of material of refractive index 1.6. The radius of curvature of the curved surface is 60 cm. The focal length of the lens is **[CBSE AIPMT 1999]**

(a) 50 cm (b) 100 cm
(c) 200 cm (d) 400 cm

Ans. *(b)*

According to Lens maker's formula, focal length of lens is given by

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$$

We know that for planoconvex lens, the radius of curvature of plane surface is infinite,

i.e. $R_2 = \infty$.

Given, $R_1 = 60$ cm, $\mu = 1.6$

Substituting the given values in Eq. (i), we get

$$\frac{1}{f} = (1.6 - 1)\left(\frac{1}{60} - \frac{1}{\infty}\right) = 0.6 \times \frac{1}{60}$$

$\therefore$ Focal length of plane convex lens

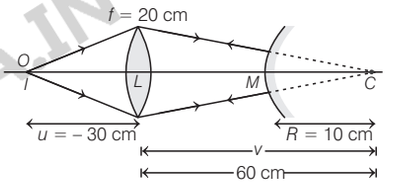
$$f = \frac{60}{0.6} = 100 \text{ cm}$$

67 A luminous object is placed at a distance of 30 cm from the convex lens of focal length 20 cm. On the other side of the lens, at what distance from the lens, a convex mirror of radius of curvature 10 cm, be placed in order to have an upright image of the object coincident with it ? **[CBSE AIPMT 1998]**

(a) 12 cm (b) 30 cm
(c) 50 cm (d) 60 cm

Ans. *(c)*

The ray diagram for the problem is shown as follows



According to lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

We have $u = -30$ cm, $f = 20$ cm

$\therefore \quad \frac{1}{20} = \frac{1}{v} - \frac{1}{-30}$

or $\frac{1}{v} = \frac{1}{20} - \frac{1}{30} = \frac{3 - 2}{60} = \frac{1}{60}$

$\therefore \quad v = 60$ cm

For the image (I) coincident with object (O), the rays after refraction from the lens must fall on the convex mirror normally or the rays refracted from lens must meet at C.

$\therefore \quad LC = v = 60$ cm

Thus, distance between lens and mirror

$LM = 60 - 10 = 50$ cm

68 The focal lengths of a converging lens measured for violet, green and red colours are f_V, f_G, f_R respectively. We will find **[CBSE AIPMT 1997]**

(a) $f_G > f_R$ (b) $f_V < f_R$
(c) $f_V > f_R$ (d) $f_V = f_R$

Ans. *(b)*

Lens maker's formula is

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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or $\frac{1}{f} \propto \mu$ or $f \propto \frac{1}{\mu}$ ...(i)

According to Cauchy's formula,

$$\mu \propto \frac{1}{\lambda} \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$f \propto \lambda$$

Hence, focal length of a converging lens is maximum for red colour (highest wavelength) and minimum for violet colour (lowest wavelength)

i.e. $f_V < f_R$

69 A convex lens of focal length 80 cm and a concave lens of focal length 50 cm are combined together. What will be their resulting power?

[CBSE AIPMT 1996]

(a) + 6.5 D (b) – 6.5 D
(c) + 7.5 D (d) – 0.75 D

Ans. *(d)*

Power of a lens is the ability of the lens to converge a beam of light falling on the lens. It is measured as the reciprocal of focal length of the lens.

i.e. $P = \frac{1}{f_{(in\,m)}}$

When f is in cm,

$$P = \frac{100}{f}\,\text{D}$$

Here, $f_1 = 80$ cm, $f_2 = -50$ cm

Combined power of two lenses in contact is given by $P_{eq} = P_1 + P_2$

$$\Rightarrow \quad P_{eq} = \frac{1}{f_1(m)} + \frac{1}{f_2(m)}$$

[f_1 and f_2 are with sign]

$$\therefore \quad P = \frac{100}{80} - \frac{100}{50} = -0.75\,\text{D}$$

70 A lens is placed between a source of light and a wall. It forms images of area A_1 and A_2 on the wall, for its two different positions, the area of the source of light is

[CBSE AIPMT 1995]

(a) $\sqrt{A_1A_2}$ (b) $\frac{A_1 + A_2}{2}$
(c) $\frac{A_1 - A_2}{2}$ (d) $\frac{1}{A_1} + \frac{1}{A_2}$

Ans. *(a)*

In displacement method, total magnification $m = \sqrt{m_1 m_2}$. Therefore, area of source is given by $A = \sqrt{A_1A_2}$.

71 Focal length of a convex lens will be maximum for

[CBSE AIPMT 1994]

(a) blue light (b) yellow light
(c) green light (d) red light

Ans. *(d)*

As wavelength of violet light λ_{violet} < Wave length of red light λ_{red}, therefore, refractive index of violet light μ_{violet} > Refractive index of red light μ_{red}.

Hence, $f_{red} > f_{violet}$

So, focal length of lens for red light is maximum than other visible spectrum of light.

72 Focal length of a convex lens of refractive index 1.5 is 2 cm. Focal length of lens when immersed in a liquid of refractive index 1.25 will be **[CBSE AIPMT 1988]**

(a) 10 cm (b) 2.5 cm
(c) 5 cm (d) 7.5 cm

Ans. *(c)*

Focal length of convex lens in air is given by

$$\frac{1}{f_a} = ({}_a\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ...(i)$$

Focal length of convex lens when immersed in liquid of refractive index μ_l is given by

$$\frac{1}{f_l} = ({}_l\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

${}_l\mu_g$ = refractive index of glass w.r.t. liquid

R_1, R_2 = radius of curvature of lens spherical surface

or $\frac{1}{f_l} = \left(\frac{\mu_g}{\mu_l} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ ...(ii)

From Eqs. (i) and (ii),

$$\frac{\frac{1}{f_a}}{\frac{1}{f_l}} = \frac{(\mu_g - 1)}{\left(\frac{\mu_g}{\mu_l} - 1\right)} \quad \text{or} \quad \frac{f_l}{f_a} = \frac{(\mu_g - 1)}{\left(\frac{\mu_g}{\mu_l} - 1\right)}$$

or $\frac{f_l}{f_a} = \frac{(1.5 - 1)}{\left(\frac{1.5}{1.25} - 1\right)} = \frac{1/2}{1/5} = \frac{5}{2}$

$$\therefore \quad f_l = \frac{5}{2} f_a = \frac{5}{2} \times 2 = 5\,\text{cm}$$

TOPIC 4
Optical Instruments

73 A lens of large focal length and large aperture is best suited as an objective of an astronomical telescope, since **[NEET 2021]**

(a) a large aperture contributes to the quality and visibility of the images
(b) a large area of the objective ensures better light gathering power
(c) a large aperture provides a better resolution
(d) All of the above

Ans. *(d)*

The objective of an astronomical telescope has large focal length and large aperture. Because the lens used is convex lens and the magnification of an astronomical telescope is directly proportional to the focal length of the objective lens.

This large aperture also contributes to the better quality and visibility of the images. Thus, it provides better resolution.

Due to large focal length of the objective, it covers large area which ensures better light gathering power.

Thus, all options (a), (b) and (c) are correct.

74 A astronomical telescope has objective and eyepiece of focal lengths 40 cm 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance **[NEET 2016]**

(a) 46.0 cm (b) 50.0 cm
(c) 54.0 cm (d) 37.3 cm

Ans. *(c)*

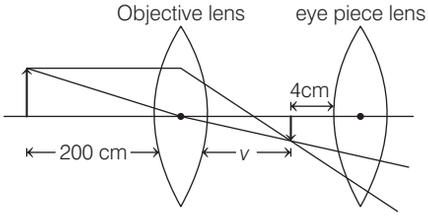
According to question,

Focal length of objective lens (F_0) = + 40 cm

Focal length of eyepiece lens (F_e) = 4 cm

Object distance for objective lens (u_0) = – 200 cm

Applying lens formula for objective lens



$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} - \frac{1}{-200} = \frac{1}{40}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{40} - \frac{1}{200} = \frac{5-1}{200} = \frac{4}{200}$$

$$\Rightarrow \quad v = 50\,\text{cm}$$

Image will be form at first focus of eyepiece lens.

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So, for normal adjustment distance between objectives and eye piece lense (length of tube) will be

$v + F_e \Rightarrow 50 + 4 \Rightarrow 54\,\text{cm}$

74 A person can see clearly objects only when they lie between 50 cm and 400 cm from his eyes. In order to increase the maximum distance of distinct vision to infinity, the type and power of the correcting lens, the person has to use, will be **[NEET 2016]**

(a) convex, + 2.25 diopter
(b) concave, – 0.25 diopter
(c) concave – 0.2 diopter
(d) convex, + 0.15 diopter

Ans. *(b)*

Key Idea Image of object at ∞ must lie within distance upto which person can view clearly.

Image distance, $v = 400\,\text{cm} = 4\,\text{m} \Rightarrow u = \infty$

Using lens equation,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{-4} - \frac{1}{\infty} = \frac{1}{f}$$

$$\Rightarrow \quad f = -4\,\text{m}$$

Now power of the required lens is,

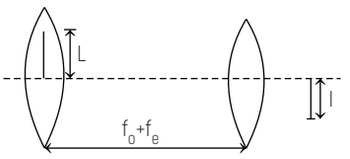
$$P = \frac{1}{f} = \frac{1}{-4} = -0.25\,\text{D}$$

Thus, the person require a concave lens of power – 0.25 D.

76 In an astronomical telescope in normal adjustment a straight black line of length L is drawn on inside part of objective lens. The eye-piece forms a real image of this line. The length of this image is l. The magnification of the telescope is **[CBSE AIPMT 2015]**

(a) $\frac{L}{l} + 1$ (b) $\frac{L}{l} - 1$ (c) $\frac{L+1}{L-1}$ (d) $\frac{L}{l}$

Ans. *(d)*



We know, magnification of telescope, we have

$$M = \frac{f_o}{f_e},$$

Here $\frac{f_e}{f_e + u} = \frac{-l}{L}$

$$\Rightarrow \quad \frac{f_e}{f_e - (f_o + f_e)} = \frac{-l}{L}$$

$$\Rightarrow \quad \frac{f_e}{f_o} = \frac{l}{L}$$

i.e. $M = \frac{L}{l}$

77 If the focal length of objective lens is increased, then magnifying power of **[CBSE AIPMT 2014]**

(a) microscope will increase but that of telescope decrease
(b) microscope and telescope both will increase
(c) microscope and telescope both will decrease
(d) microscope will decrease but that of telescope will increase

Ans. *(d)*

For microscope, $m = \frac{L}{f_o}\frac{D}{f_e} \Rightarrow m \propto \frac{1}{f_o}$

For telescope, $m = \frac{f_o}{f_e}$

$$m \propto f_o$$

The magnifying power of microscope will decrease but the magnifying power of telescope will increase.

78 For a normal eye, the cornea of eye provides a converging power of 40 D and the least converging power of the eye lens behind the cornea is 20 D. Using this information, the distance between the retina and the cornea, eye lens can be estimated to be **[NEET 2013]**

(a) 5 cm (b) 2.5 cm
(c) 1.67 cm (d) 1.5 cm

Ans. *(c)*

Given, power $(P_1) = 40\,\text{D}$ and power $(P_2) = 20\,\text{D}$

We have $P_{eq} = P_1 + P_2$

$$= 40 + 20 = 60\,\text{D}$$

So, $\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$

$$\Rightarrow \quad f_{eq} = \frac{100}{P_{eq}} = \frac{100}{60} = 1.67\,\text{cm}$$

79 The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are **[CBSE AIPMT 2012]**

(a) 10 cm, 10 cm (b) 15 cm, 5 cm
(c) 18 cm, 2 cm (d) 11 cm, 9 cm

Ans. *(c)*

Given, Magnification $= \frac{f_o}{f_e} = 9$

and $f_o + f_e = 20$

$$f_o = 9f_e$$

So, $9f_e + f_e = 20$

$$f_e = 2\,\text{cm}$$

$\therefore \quad f_o = 9 \times 2$

$$f_o = 18\,\text{cm}$$

80 A microscope is focussed on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again ? **[CBSE AIPMT 2006]**

(a) 1 cm upward
(b) 4.5 cm downward
(c) 1 cm downward
(d) 2 cm upward

Ans. *(a)*

Apparent depth of mark as seen through a glass slab of thickness x and refractive index μ is

$$\text{Apparent depth} = \frac{\text{real depth}}{\text{refractive index}}$$

or $x' = \frac{x}{\mu} = \frac{3}{1.5} = 2\,\text{cm}$

As image appears to be raised by 1 cm, therefore, microscope must be moved upward by 1 cm.

81 A telescope has an objective lens of 10 cm diameter and is situated at a distance of one kilometre from two objects. The minimum distance between these two objects, which can be resolved by the telescope, when the mean wavelength of light is 5000 Å, is of the order of **[CBSE AIPMT 2004]**

(a) 0.5 m (b) 5 m
(c) 5 mm (d) 5 cm

Ans. *(c)*

Resolving limit of telescope is given by

$$\theta \propto \frac{x}{D} = \frac{\lambda}{d}$$

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λ = wavelength
d = diagram of objective lens of telescope
D = Distance between object and telescope

$$\Rightarrow \quad x = \frac{\lambda D}{d}$$

Given, $\lambda = 5000\ \text{Å} = 5000 \times 10^{-10}$ m,
$D = 1\,\text{km} = 1000$ m,
$d = 10\ \text{cm} = 0.1\,\text{m}$

Hence, $$x = \frac{5000 \times 10^{-10} \times 1000}{0.1}$$
$$= 5 \times 10^{-3}\ \text{m} = 5\,\text{mm}$$

82 Diameter of human eye lens is 2 mm. What will be the minimum distance between two points to resolve them, which are situated at a distance of 50 m from eye ? [The wavelength of light is 5000 Å] **[CBSE AIPMT 2002]**

(a) 2.32 m (b) 4.28 mm
(c) 1.25 cm (d) 12.48 cm

Ans. *(c)*

Angular limit of resolution of eye
$$= \frac{\text{wavelength of light}}{\text{diameter of eye lens}}$$

i.e. $$\theta = \frac{\lambda}{d} \qquad ...(i)$$

If y is the minimum distance between two points at distance D from eye, then
Angular limit of resolution of eye
$$\theta = \frac{y}{D} \qquad ...(ii)$$

From Eqs. (i) and (ii), we have
$$\frac{y}{D} = \frac{\lambda}{d}$$

or $$y = \frac{\lambda D}{d} \qquad ...(iii)$$

Given, $\lambda = 5000\,\text{Å} = 5 \times 10^{-7}$ m, $D = 50$ m,
$d = 2\,\text{mm} = 2 \times 10^{-3}$ m
Substituting in Eq. (iii), we get
$$y = \frac{5 \times 10^{-7} \times 50}{2 \times 10^{-3}}$$
$$= 12.5 \times 10^{-3}\ \text{m}$$
$$= 1.25\ \text{cm}$$

83 An astronomical telescope of ten-fold angular magnification has a length of 44 cm. The focal length of the objective is **[CBSE AIPMT 1997]**

(a) 440 cm (b) 44 cm
(c) 40 cm (d) 4 cm

Ans. *(c)*

For an astronomical telescope,
where magnification, $m = \frac{f_o}{f_e}$

f_0 = focal length of objective lens
f_e = focal length of eye piece lens
Length of telescope tube $L = f_o + f_e$
Given, $m = 10$, $L = 44$ cm

$$\therefore \quad \frac{f_o}{f_e} = 10$$

and $$f_o + f_e = 44$$

$$\Rightarrow \quad f_e = \frac{f_o}{10}$$

So, $$f_o + \frac{f_o}{10} = 44$$

or $$\frac{11 f_o}{10} = 44$$

or $$f_o = 40\ \text{cm}$$

84 The hypermetropia is a **[CBSE AIPMT 1995]**

(a) short-sight defect
(b) long-sight defect
(c) bad vision due to old age
(d) None of the above

Ans. *(b)*

A hypermetropic person or a long sighted person can see clearly only those objects which are at long distances, as if near point of his eye has shifted to some distant point. This defect arises on account of contraction of eye ball or increase in focal length of eye lens. To correct this defect, the person has to wear specs using a convex lens of suitable focal length given by

$$\frac{1}{f} = \frac{1}{D} - \frac{1}{d}$$

where d = actual distance of distinct vision of defective eye, and
D = distance of distinct vision of normal eye.

Note A myopic person can see clearly only those objects which are at short distances from the eye. This is as if far point of the eye has shifted to some nearby point.

Oldage vision defect is also called astigmatism. It arises because curvature of the cornea plus eye lens refracting system is not the same in different planes. This defect is removed by using a cylindrical lens with its axis along the vertical.

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Wave Optics

TOPIC 1
Huygen's Principle and and Interefernce of Light

01 Two coherent sources of light interfere and produce fringe pattern on a screen. For central maximum, the phase difference between the two waves will be **[NEET (Oct.) 2020]**

(a) zero (b) π
(c) $3\pi/2$ (d) $\pi/2$

Ans. *(a)*

For central maximum, path difference is zero for both coherent sources in interference.

Hence, phase difference $= \frac{2\pi}{\lambda} \times$ path difference

$$= \frac{2\pi}{\lambda} \times 0 = 0$$

02 In Young's double slit experiment, if the separation between coherent sources is halved and the distance of the screen from the coherent sources is doubled, then the fringe width becomes **[NEET (Sep.) 2020]**

(a) half (b) four times
(c) one-fourth (d) double

Ans. *(b)*

Fringe width, $\beta = \frac{\lambda D}{d}$

$$\therefore \quad \frac{\beta_2}{\beta_1} = \frac{\frac{\lambda_2 D_2}{d_2}}{\frac{\lambda_1 D_1}{d_1}}$$

$$\left[\text{As } \lambda_1 = \lambda_2,\ D_2 = 2D_1 \text{ and } d_2 = \frac{d_1}{2}\right]$$

$$\therefore \quad \frac{\beta_2}{\beta_1} = \frac{2D_1}{\left(\frac{d_1}{2}\right)} \times \frac{d_1}{D_1} = 4$$

$$\Rightarrow \quad \beta_2 = 4\beta_1$$

i.e., fringe width becomes four times.

Hence, correct option is (b).

03 In a Young's double slit experiment, if there is no initial phase-difference between the light from the two slits, a point on the screen corresponding to the fifth minimum has path difference. **[NEET (Odisha) 2020]**

(a) $5\frac{\lambda}{2}$ (b) $10\frac{\lambda}{2}$
(c) $9\frac{\lambda}{2}$ (d) $11\frac{\lambda}{2}$

Ans. *(c)*

In a *YDSE*, the path difference for *n*th minima is given by

$$\Delta y = (2n-1)\frac{\lambda}{2}$$

For 5th minima, $n = 5$

$$\therefore \quad \Delta y = [2(5)-1]\frac{\lambda}{2} = \frac{9\lambda}{2}$$

04 In a double slit experiment, when light of wavelength 400 nm was used, the angular width of the first minima formed on a screen placed 1 m away, was found to be 0.2º. What will be the angular width of the first minima, if the entire experimental apparatus is immersed in water? ($\mu_{water} = 4/3$) **[NEET (National) 2019]**

(a) 0.15º (b) 0.051°
(c) 0.1º (d) 0.266º

Ans. *(a)*

The angular width in YDSE is given by

$$\theta = \frac{\beta}{D}$$

where, β is the separation between two fringes. D is the distance between the planed the slits and screen. If YDSE apparatus is immersed in a liquid of refractive index μ, then the wavelength of light and hence the angular width decreases μ times.

i.e.

and $$\theta' = \frac{\beta}{\mu D} = \frac{\theta}{\mu}$$

Here, μ (for water) $= 4/3$ and

$$\theta = 0.2°$$

$$\Rightarrow \quad \theta' = \frac{0.2}{4/3} = 0.15°$$

05 In Young's double slit experiment, the separation *d* between the slits is 2 mm, the wavelength λ of the light used is 5896 Å and distance *D* between the screen and slits is 100 cm. It is found that the angular width of the fringes is 0.20°. To increase the fringe angular width to 0.21° (with same λ and *D*) the separation between the slits needs to be changed to **[NEET 2018]**

(a) 2.1 mm (b) 1.9 mm
(c) 1.8 mm (d) 1.7 mm

Ans. *(b)*

In a YDSE, angular width of a fringe is given as

$$\theta = \frac{\lambda}{d}$$

where, λ is the wavelength of the light source and *d* is the distance between the two slits.

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$\Rightarrow \quad \theta \propto \frac{1}{d}$

or $\frac{\theta_1}{\theta_2} = \frac{d_2}{d_1}$ ...(i)

Here, $\theta_1 = 0.20°, \theta_2 = 0.21°$,
$d_1 = 2\,\text{mm}$

Substituting the given values in Eq. (i), we get

$\frac{0.20°}{0.21°} = \frac{d_2}{2\,\text{mm}}$

$\Rightarrow \quad d_2 = 2 \times \frac{0.20}{0.21} = \frac{0.40}{0.21}$

$\therefore \quad = 1.90\ \text{mm}$

06 Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8th bright fringe in the medium lies where 5th dark fringe lies in air. The refractive index of the medium is nearly **[NEET 2017]**

(a) 1.25 (b) 1.59
(c) 1.69 (d) 1.78

Ans. *(d)*

According to question,

5th dark fringe in air = 8 bright fringe in the medium

$(2 \times 5 - 1)\frac{\lambda D}{2d} = 8\frac{\lambda D}{\mu d} \Rightarrow 9\frac{\lambda D}{2d} = 8\frac{\lambda D}{\mu d}$

$\Rightarrow \quad \frac{9}{2} = \frac{8}{\mu} \Rightarrow \mu = \frac{8 \times 2}{9}$

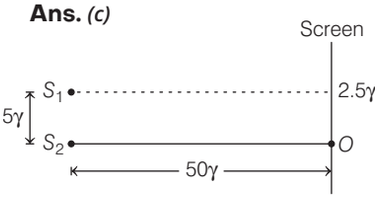
$\therefore$ Refractive index of the medium,

$\mu = \frac{16}{9} = 1.7777 \approx 1.78$

07 The intensity at the maximum in a Young's double slit experiment is I_0. Distance between two slits is $d = 5\lambda$, where λ is the wavelength of light used in the experiment. What will be the intensity infront of one of the slits on the screen placed at a distance $D = 10\,d$? **[NEET 2016]**

(a) $\frac{I_0}{4}$ (b) $\frac{3}{4}I_0$
(c) $\frac{I_0}{2}$ (d) I_0

Ans. *(c)*



In the above figure, S_1 and S_2 are the two different slits.

Given, distance between slits S_1 and S_2,

$d = 5\lambda$

distance between screen and slits,

$D = 10d = 50\lambda$

Here, λ is the wavelength of light used in the experiment.

According to question, the intensity at maximum in this Young's double slit experiment is I_0.

$\Rightarrow \quad I_{max} = I_0$

$\because$ Path difference

$= \frac{dY_n}{D} = \frac{d \times \frac{d}{2}}{10d} = \frac{d}{20} = \frac{\lambda}{4}$

$\{\because d = 5\lambda\}$

A path difference of λ corresponds to phase difference 2π

So, for path difference $\lambda/4$, phase difference

$\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \pi/2 = 90°$

As we know, $I = I_0 \cos^2 \frac{\phi}{2}$

$\Rightarrow \quad I = I_0 \cos^2 \frac{90°}{2}$

$\Rightarrow \quad I = I_0 \times \left(\frac{1}{\sqrt{2}}\right)^2 \Rightarrow I = \frac{I_0}{2}$

08 The interference pattern is obtained with two coherent light sources of intensity ratio *n*. In the interference pattern, the ratio $\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$ will be **[NEET 2016]**

(a) $\frac{\sqrt{n}}{n+1}$ (b) $\frac{2\sqrt{n}}{n+1}$
(c) $\frac{\sqrt{n}}{(n+1)^2}$ (d) $\frac{2\sqrt{n}}{(n+1)^2}$

Ans. *(b)*

It is given that, $\frac{I_2}{I_1} = n \Rightarrow I_2 = nI_1$

$\therefore$ Ratio of intensities is given by

$\frac{I_{max} - I_{min}}{I_{max + I_{min}}} = \frac{(\sqrt{I_2} + \sqrt{I_1})^2 - (\sqrt{I_2} - \sqrt{I_1})^2}{(\sqrt{I_1} + \sqrt{I_2})^2 + (\sqrt{I_2} - \sqrt{I_1})^2}$

$= \frac{\left(\sqrt{\frac{I_2}{I_1}} + 1\right)^2 - \left(\sqrt{\frac{I_2}{I_1}} - 1\right)^2}{\left(\sqrt{\frac{I_2}{I_1}} + 1\right)^2 + \left(\sqrt{\frac{I_2}{I_1}} - 1\right)^2}$

$= \frac{(\sqrt{n}+1)^2 - (\sqrt{n}-1)^2}{(\sqrt{n}+1)^2 + (\sqrt{n}-1)^2} = \frac{2\sqrt{n}}{n+1}$

09 In a double slit experiment, the two slits are 1 mm apart and the screen is placed 1 m away. A monochromatic light of wavelength 500 nm is used. What will be the width of each slit for obtaining ten maxima of double slit within the central maxima of single slit pattern? **[CBSE AIPMT 2015]**

(a) 0.2 mm (b) 0.1 mm
(c) 0.5 mm (d) 0.02 mm

Ans. *(a)*

Given $d = 1\,\text{mm} = 1 \times 10^{-3}\,\text{m}$

$D = 1\,\text{m}, \lambda = 500\,\text{nm} = 5 \times 10^{-7}\ \text{m}$

As width of central maxima = width of 10 maxima

$\therefore \quad \frac{2D\lambda}{a} = 10\left(\frac{\lambda D}{d}\right)$

$\Rightarrow \quad a = \frac{d}{5} = \frac{10^{-3}}{5} = 0.2 \times 10^{-3}\,\text{m}$

$a = 0.2\,\text{mm}$

10 Two slits in Youngs experiment have widths in the ratio 1 : 25. The ratio of intensity at the maxima and minima in the interference pattern $\frac{I_{max}}{I_{min}}$ is **[CBSE AIPMT 2015]**

(a) $\frac{9}{4}$ (b) $\frac{121}{49}$
(c) $\frac{49}{121}$ (d) $\frac{4}{9}$

Ans. *(a)*

Given, YDSE experiment, having two slits of width are in the ratio of 1 : 25.

So, ratio of intensity,

$\frac{I_1}{I_2} = \frac{W_1}{W_2} = \frac{1}{25} \Rightarrow \frac{I_2}{I_1} = \frac{25}{1}$

$\therefore \frac{I_{max}}{I_{min}} = \frac{(\sqrt{I_2} + \sqrt{I_1})^2}{(\sqrt{I_2} - \sqrt{I_1})^2} = \left[\frac{\sqrt{\frac{I_2}{I_1}} + 1}{\sqrt{\frac{I_2}{I_1}} - 1}\right]^2$

$\Rightarrow \left[\frac{5+1}{5-1}\right]^2 = \left(\frac{6}{4}\right)^2 = \frac{36}{16} = \frac{9}{4}$

Thus, $\frac{I_{max}}{I_{min}} = \frac{9}{4}$

11 In the Young's double-slit experiment, the intensity of light at a point on the screen (where the path difference is λ) is *K*, (λ being the wavelength of light

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used). The intensity at a point where the path difference is $\lambda/4$, will be **[CBSE AIPMT 2014]**

(a) K (b) $K/4$
(c) $K/2$ (d) zero

Ans. *(c)*

For net intensity

$$I' = 4I_0 \cos^2 \frac{\phi}{2}$$

For the first case, $K = 4I_0 \cos^2[\pi]$ $\because \left(\phi = \frac{2\pi}{\lambda} \times \lambda\right)$

$$K = 4I_0 \quad ...(i)$$

For the second case,

$$K' = 4I_0 \cos^2\left(\frac{\pi/2}{2}\right)$$

$\because \left(\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{4}\right)$

$$K' = 2I_0 \quad ...(ii)$$

Comparing Eqs. (i) and (ii), we get

$$K' = \frac{K}{2}$$

12 In Young's double slit experiment, the slits are 2 mm apart and are illuminated by photons of two wavelengths $\lambda_1 = 12000$ Å and $\lambda_2 = 10000$ Å. At what minimum distance from the common central bright fringe on the screen 2 m from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other? **[NEET 2013]**

(a) 8 mm (b) 6 mm
(c) 4 mm (d) 3 mm

Ans. *(b)*

Given, $\lambda_1 = 12000$ Å and $\lambda_2 = 10000$ Å, $D = 2$ m and $d = 2$ mm $= 2 \times 10^{-3}$ m.

Fringe-width of first wavelength,

$$\beta_1 = \frac{\lambda_1 D}{d} = \frac{12000 \times 10^{-10} \times 2}{2 \times 10^{-3}} = 1.2 \text{ mm}$$

Fringe-width of second waveleng th,

$$\beta = \frac{\lambda_2 D}{d} = \frac{10000 \times 10^{-10} \times 2}{2 \times 10^{-3}} = 1 \text{mm}$$

At 6 mm distance from central bright fringe, 5th fringe of first wavelength coincide with 6th fringe of second wavelength.

13 Colours of thin soap bubbles are due to **[CBSE AIPMT 1999]**

(a) refraction
(b) dispersion
(c) interference
(d) diffraction

Ans. *(c)*

When white light is incident on a soap bubble it is partly reflected from upper surface and partly reflected from lower surface. These two reflected beams superpose to cause interference. The colours which satisfy the condition of maxima are visible in reflected light. So, colours of soap bubbles are caused due to interference.

TOPIC 2
Diffraction and Polarisation of Light

14 Assume that, light of wavelength 600 nm is coming from a star. The limit of resolution of telescope whose objective has a diameter of 2 m is **[NEET (Sep.) 2020]**

(a) 1.83×10^{-7} rad (b) 7.32×10^{-7} rad
(c) 6.00×10^{-7} rad (d) 3.66×10^{-7} rad

Ans. *(d)*

Given, light of wavelength, $\lambda = 600$ nm $= 600 \times 10^{-9}$ m

Diameter, $d = 2$ m

As, limit of resolution of telescope,

$$d\theta = \frac{1.22\lambda}{d} = \frac{1.22 \times 600 \times 10^{-9}}{2} = 3.66 \times 10^{-7} \text{ rad}$$

Hence, correct option is (d).

15 The Brewster's angle i_b for an interface should be **[NEET (Sep.) 2020]**

(a) $30° < i_b < 45°$ (b) $45° < i_b < 90°$
(c) $i_b = 90°$ (d) $0° < i_b < 30°$

Ans. *(b)*

The Brewster's angle i_b for an interface should lies between 45° to 90°, i.e. $45° < i_b < 90°$.

Hence, correct option is (b).

16 Angular width of the central maxima in the Fraunhoffer diffraction for $\lambda = 6000$ Å is θ_0. When the same slit is illuminated by another monochromatic light, the angular width decreases by 30%. The wavelength of this light is **[NEET (Odisha) 2019]**

(a) 1800 Å (b) 4200 Å
(c) 6000 Å (d) 420 Å

Ans. *(b)*

The angular width of central maxima is given by

$$2\theta = \frac{2\lambda}{a} \quad ...(i)$$

where, λ = wavelength of light used

a = width of the slit

For $\lambda_1 = 6000$ Å, $2\theta = \theta_0$ (given)

For another light of wavelength λ_2 (says), the angular width decreases by 30% so,

$$2\theta = \left(\frac{100 - 30}{100}\right)\theta_0 = \frac{70}{100}\theta_0 = 0.7\theta_0$$

As slit width is constant, so using Eq. (i) for these values, we get

$$\frac{\theta_0}{0.7\theta_0} = \frac{\lambda_1}{\lambda_2}$$

$$\Rightarrow \quad \lambda_2 = \lambda_1 \times 0.7 = 6000 \times 0.7 = 4200 \text{ Å}$$

17 An astronomical refracting telescope will have large angular magnification and high angular resolution, when it has an objective lens of **[NEET 2018]**

(a) large focal length and large diameter
(b) large focal length and small diameter
(c) small focal length and large diameter
(d) small focal length and small diameter

Ans. *(c)*

Angular magnification of an astronomical refracting telescope is given as

$$M = \frac{f_0}{f_e}$$

where, f_0 and f_e are the focal length of objective and eye-piece, respectively.

From the given relation, it is clear that for large magnification either f_0 has to be large or f_e has to be small.

Angular resolution of an astronomical refracting telescope is given as

$$R = \frac{a}{1.22\lambda}$$

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where, a is the diameter of the objective.

Thus, to have large resolution, the diameter of the objective should be large.

Hence, from the above objective lens should have large focal length (f_0) and large diameter (a).

18 Unpolarised light is incident from air on a plane surface of a material of refractive index 'μ'. At a particular angle of incidence 'i', it is found that the reflected and refracted rays are perpendicular to each other. Which of the following options is correct for this situation? **[NEET 2018]**

(a) $i = \sin^{-1}\left(\frac{1}{\mu}\right)$

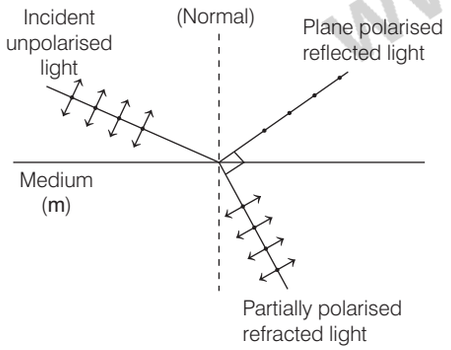
(b) Reflected light is polarised with its electric vector perpendicular to the plane of incidence

(c) Reflected light is polarised with its electric vector parallel to the plane of incidence

(d) $i = \tan^{-1}\left(\frac{1}{\mu}\right)$

Ans. *(b)*

The figure shown below represents the course of path an unpolarised light follows when it is incident from air on plane surface of material of refractive index μ.



When the beam of unpolarised light is reflected from a medium (refractive index = μ) and if reflected and refracted light are perpendicular to each other. Then, the reflected light is completely plane polarised at a certain angle of incidence. This means, the reflected light has electric vector perpendicular to incidence plane.

19 The ratio of resolving powers of an optical microscope for two wavelengths $\lambda_1 = 4000\,\text{Å}$ and $\lambda_2 = 6000\,\text{Å}$ is **[NEET 2017]**

(a) 8 : 27 (b) 9 : 4
(c) 3 : 2 (d) 16 : 81

Ans. *(c)*

As, resolving power of a microscope,

$$(\text{RP}) \propto \frac{1}{\lambda_{(\text{wavelength})}}$$

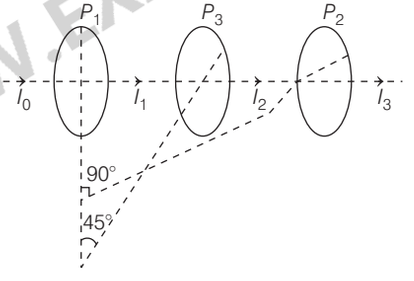
$$\therefore \quad \frac{\text{RP}_1}{\text{RP}_2} = \frac{\lambda_2}{\lambda_1} = \frac{6000}{4000} = \frac{3}{2}$$

20 Two polaroids P_1 and P_2 are placed with their axis perpendicular to each other. Unpolarised light I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its axis makes an angle 45° with that of P_1. The intensity of transmitted light through P_2 is **[NEET 2017]**

(a) $\frac{I_0}{2}$ (b) $\frac{I_0}{4}$
(c) $\frac{I_0}{8}$ (d) $\frac{I_0}{16}$

Ans. *(c)*

According to the question



From the above diagram, intensity transmitted through P_3

$$I_2 = \frac{I_0}{2}\cos^2 45° \Rightarrow I_2 = \frac{I_0}{2} \times \left(\frac{1}{\sqrt{2}}\right)^2$$

$$\Rightarrow \quad I_2 = \frac{I_0}{4}$$

Similarly, intensity transmitted through P_2,

$$I_3 = \frac{I_0}{4}\cos^2 45°$$

$$\Rightarrow \quad I_3 = \frac{I_0}{4} \times \left(\frac{1}{\sqrt{2}}\right)^2$$

$$\Rightarrow \quad I_3 = \frac{I_0}{4} \times \frac{1}{2} \Rightarrow I_3 = \frac{I_0}{8}$$

21 In a diffraction pattern due to a single slit of width a, the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. The first secondary maximum is observed at an angle of **[NEET 2016]**

(a) $\sin^{-1}\left(\frac{2}{3}\right)$ (b) $\sin^{-1}\left(\frac{1}{2}\right)$
(c) $\sin^{-1}\left(\frac{3}{4}\right)$ (d) $\sin^{-1}\left(\frac{1}{4}\right)$

Ans. *(c)*

As the first minimum is observed at an angle of 30° in a diffraction pattern due to a single slit of width a.

i.e. $n = 1,\ \theta = 30°$

∵ According to Bragg's law of diffraction,

$$a\sin\theta = n\lambda \Rightarrow a\sin 30° = (1)\,\lambda\ (n = 1)$$

$$\Rightarrow \quad a = 2\lambda \qquad \ldots(\text{i})$$

$$\left\{\because \sin 30° = \frac{1}{2}\right\}$$

For Ist secondary maxima

$$\Rightarrow a\sin\theta_1 = \frac{3\lambda}{2} \Rightarrow \sin\theta_1 = \frac{3\lambda}{2a} \qquad \ldots(\text{ii})$$

Substitute value of a from Eq. (i) to Eq. (ii), we get

$$\sin\theta_1 = \frac{3\lambda}{4\lambda} \Rightarrow \sin\theta_1 = \frac{3}{4}$$

$$\Rightarrow \quad \theta_1 = \sin^{-1}\left(\frac{3}{4}\right)$$

22 A linear aperture whose width is 0.02 cm is placed immediately in front of a lens of focal length 60 cm. The aperture is illuminated normally by a parallel beam of wavelength 5×10^{-5} cm. The distance of the first dark band of the diffraction pattern from the centre of the screen is **[NEET 2016]**

(a) 0.10 cm (b) 0.25 cm
(c) 0.20 cm (d) 0.15 cm

Ans. *(d)*

Key Idea Ist minima is formed at a distance $Y = \frac{\lambda D}{a}$

For the distance of the first dark band of the diffraction pattern from the centre of the screen is given by positon of Ist minima.

i.e. $Y = \frac{\lambda D}{a}$

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where, λ = wavelength of parallel beams

D = focal length

a = width of linear aperture.

$\Rightarrow Y = \frac{(5\times10^{-5})(0.6)}{0.02\times10^{-2}}$ (given)

$\Rightarrow Y = 0.15$ cm

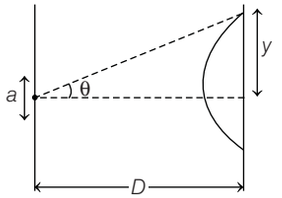
23 For a parallel beam of monochromatic light of wavelength 'λ' diffraction is produced by a single slit whose width 'a' is of the order of the wavelength of the light. If 'D' is the distance of the screen from the slit, the width of the central maxima will be **[CBSE AIPMT 2015]**

(a) $\frac{2D\lambda}{a}$ (b) $\frac{D\lambda}{a}$

(c) $\frac{Da}{\lambda}$ (d) $\frac{2Da}{\lambda}$

Ans. ***(a)***

For the condition of maxima



$\sin\theta = \frac{\lambda}{a}$

From the geometry, $\sin\theta = \theta = \frac{Y}{D}$ (for small angle)

So, $\frac{Y}{D} = \frac{\lambda}{a}$

$\Rightarrow Y = \frac{\lambda D}{a}$

Hence, width of central maxima $= 2Y = \frac{2\lambda D}{a}$

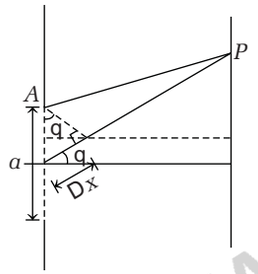
24 At the first minimum adjacent to the central maximum of a single slit diffraction pattern, the phase difference between the Huygen's wavelet from the edge of the slit and the wavelet from the midpoint of the slit is **[CBSE AIPMT 2015]**

(a) $\frac{\pi}{4}$ radian (b) $\frac{\pi}{2}$ radian

(c) π radian (d) $\frac{\pi}{8}$ radian

Ans. ***(c)***

For first minima at P, $a\sin\theta = n\lambda$



where, $N = 1 \Rightarrow a\sin\theta = \lambda$

So, phase difference,

$\Delta\phi_1 = \frac{\Delta x_1}{\lambda}\times2\pi = \frac{(a/2)\sin\theta}{\lambda}\times2\pi$

$= -\frac{\lambda}{2\lambda}\times2\pi = \pi$ rad

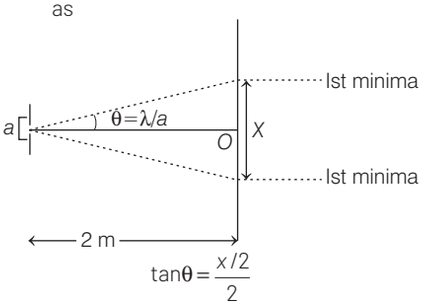
25 A beam of light of $\lambda = 600$ nm from a distant source falls on a single slit 1 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between first dark fringes on either side of the central bright fringe is **[CBSE AIPMT 2014]**

(a) 1.2 cm (b) 1.2 mm

(c) 2.4 cm (d) 2.4 mm

Ans. ***(d)***

According to question diagram is shown as



$\tan\theta = \frac{x/2}{2}$

For small θ and when θ is counted in rad, $\tan\theta \approx \theta$

So, $\theta = \frac{x/2}{2} \Rightarrow \frac{\lambda}{a} = \frac{x}{4}$

$\Rightarrow x = \frac{4\lambda}{a} = \frac{4\times600\times10^{-9}}{10^{-3}}$

$= 24\times10^{-4}$ m

$= 2.4\times10^{-3}$ m $= 2.4$ mm

26 The angular resolution of a 10 cm diameter telescope at a wavelength of 5000 Å is of the order of **[CBSE AIPMT 2005]**

(a) 10^6 rad (b) 10^{-2} rad

(c) 10^{-4} rad (d) 10^{-6} rad

Ans. ***(d)***

Angular resolution of telescope is given by

$= \frac{1.22\lambda}{d} = \frac{1.22\times5000\times10^{-10}}{10\times10^{-2}}$

$= 6.1\times10^{-6} \approx 10^{-6}$ rad

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25

Dual Nature of Radiation and Matter

TOPIC 1
Photoelectric Effect

01 Light of frequency 1.5 times the threshold frequency is incident on a photosensitive material. What will be the photoelectric current if the frequency is halved and intensity is doubled? **[NEET (Sep.) 2020]**

(a) Four times (b) One-fourth
(c) Zero (d) Doubled

Ans. *(c)*

Initially, frequency of light, $\nu = 1.5\nu_0$

But when the frequency of incident light is halved, then $\nu' = \frac{\nu}{2} = 0.75\nu_0$. Thus, it becomes less than the threshold frequency. In that case, no photoelectric effect takes place. Hence, photoelectric current becomes zero.

Hence, correct option is (c).

02 The work function of a photosensitive material is 4.0 eV. This longest wavelength of light that can cause photon emission from the substance is (approximately) **[NEET (Odisha) 2019]**

(a) 3100 nm (b) 966 nm
(c) 31 nm (d) 310 nm

Ans. *(d)*

The work function of material is given by

$$\phi = h\nu$$

$$\phi = \frac{hc}{\lambda} \quad ...(i) \left[\because \nu = \frac{c}{\lambda}\right]$$

where, h = Planck's constant $= 6.63 \times 10^{-34}$ J-s

c = speed of length $= 3 \times 10^8$ ms^{-1}

and λ = wavelength of light

Here, $\phi = 4$ eV $= 4 \times 1.6 \times 10^{-19}$ J

Substituting the given values in Eq. (i), we get

$$\Rightarrow 4 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda}$$

or $$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4 \times 1.6 \times 10^{-19}}$$

$$= 3.108 \times 10^{-7} \text{ m} = 310 \text{ nm}$$

03 When the light of frequency $2\nu_0$ (where, ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2. The ratio of v_1 to v_2 is **[NEET 2018]**

(a) 4 : 1 (b) 1 : 4
(c) 1 : 2 (d) 2 : 1

Ans. *(c)*

According to the Einstein's photoelectric equation,

$$K_{max} = \frac{1}{2} m v_{max}^2 = h\nu - \phi_0$$

$$= h\nu - h\nu_0 \quad ...(i)$$

where, K_{max} is the maximum kinetic energy of photoelectrons having maximum velocity v_{max}.

When incident frequency of light, $\nu = 2\nu_0$

Substituting the value of ν in Eq. (i), we get

$$\frac{1}{2} m v_1^2 = h(2\nu_0) - h\nu_0$$

$$= 2h\nu_0 - h\nu_0 = h\nu_0 \quad ...(ii)$$

If incident frequency of radiation, $\nu = 5\nu_0$

Substituting the value of ν in Eq. (i), we get

$$\frac{1}{2} m v_2^2 = h(5\nu_0) - h\nu_0$$

$$= 5h\nu_0 - h\nu_0 = 4h\nu_0 \quad ...(iii)$$

On dividing Eq. (ii) by Eq (iii), we get

$$\frac{\frac{1}{2} m v_1^2}{\frac{1}{2} m v_2^2} = \frac{h\nu_0}{4h\nu_0}$$

$$\Rightarrow \frac{v_1^2}{v_2^2} = \frac{1}{4} \text{ or } \frac{v_1}{v_2} = \frac{1}{2}$$

$$\therefore v_1 : v_2 = 1 : 2$$

04 The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2536×10^{-10} m is (Given, $h = 4.14 \times 10^{-15}$ eVs and $c = 3 \times 10^8$ ms^{-1}) **[NEET 2017]**

(a) $\approx 6 \times 10^5$ ms^{-1} (b) $\approx 0.6 \times 10^6$ ms^{-1}
(c) $\approx 61 \times 10^3$ ms^{-1} (d) $\approx 0.3 \times 10^6$ ms^{-1}

Ans. *(a, b)*

Thinking Process Applying Einstein's photoelectric equation, kinetic energy of emitted electron can be given by

$$K = \frac{1}{2} m v^2 = h\nu - h\nu_0 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

Given threshold wavelength,

$$\lambda_0 = 3250 \times 10^{-10} \text{ m}$$

Wavelength of ultraviolet light,

$$\lambda = 2536 \times 10^{-10} \text{ m}$$

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Let, velocity of ejected electron be v.

Now, applying Einstein's photoelectric equation, we have

$$E = K + \phi_0$$

$$\Rightarrow \quad h\nu = \frac{1}{2} m_e v^2 + h\nu_0$$

$$\Rightarrow \frac{1}{2} m_e v^2 = h\nu - h\nu_0$$

$$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

$\Rightarrow$ Velocity of electron

$$v = \sqrt{\frac{2hc}{m_e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)}$$

$$= \sqrt{\frac{2 \times 4.14 \times 10^{-15} \times 1.6 \times 10^{-19} \times 3 \times 10^8}{9.1 \times 10^{-31}} \left(\frac{3250 - 2536}{3250 \times 2536}\right)}$$

$$= 0.6 \times 10^6 \text{ ms} = 6 \times 10^5 \text{ ms}^{-1}$$

05 When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$. The threshold wavelength for the metallic surface is **[NEET 2016]**

(a) 5λ (b) $\frac{5}{2}\lambda$

(c) 3λ (d) 4λ

Ans. *(c)*

In Ist case, when a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V.

So, photoelectric equation can be written as

$$eV = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \qquad ...(i)$$

In IInd case, when the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$. So,

photoelectric equation can be written as

$$\frac{eV}{4} = \frac{hc}{2\lambda} - \frac{hc}{\lambda_0}$$

$$\Rightarrow \quad eV = \frac{4hc}{2\lambda} - \frac{4hc}{\lambda_0} \qquad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\Rightarrow \quad \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{4hc}{2\lambda} - \frac{4hc}{\lambda_0}$$

$$\Rightarrow \quad \frac{1}{\lambda} - \frac{1}{\lambda_0} = \frac{2}{\lambda} - \frac{4}{\lambda_0}$$

$$\Rightarrow \quad \lambda_0 = 3\lambda$$

06 Photons with energy 5 eV are incident on a cathode C in a photoelectric cell. The maximum energy of emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A, if the stopping potential of A relative to C is **[NEET 2016]**

(a) + 3 V (b) + 4 V (c) – 1 V (d) – 3 V

Ans. *(d)*

Key Idea Use Einstein's photoelectric equation.

We know that, $E = (\text{KE})_{max}$ + Work function (ϕ)

where, $\phi = h\nu_0$, $E = h\nu$

$$(\text{KE})_{max} = \frac{1}{2} m v_0^2$$

$$\Rightarrow \quad (\text{KE})_{max} = h\nu - \phi$$

$$\Rightarrow \quad 2\text{eV} = 5\text{eV} - \phi \qquad \text{(given)}$$

$$\Rightarrow \quad \phi = 3\text{eV}$$

Thus, $V_{cathode} - V_{anode} = 3\text{ V}$

$$\Rightarrow \quad V_{anode} - V_{cathode} = -3\text{ V}$$

07 A certain metallic surface is illuminated with monochromatic light of wavelength λ. The stopping potential for photoelectric current for this light is $3V_0$. If the same surface is illuminated with light of wavelength 2λ, the stopping potential is V_0. The threshold wavelength for this surface for photoelectric effect is **[CBSE AIPMT 2015]**

(a) 6λ (b) 4λ (c) $\frac{\lambda}{4}$ (d) $\frac{\lambda}{6}$

Ans. *(b)*

From photoelectric equation

$h\nu = W + eV_0$

(where, W = work function)

So $$\frac{hc}{\lambda} = W + 3eV_0 \qquad ...(i)$$

Also, $$\frac{hc}{2\lambda} = W + eV_0$$

$$\Rightarrow \quad \frac{hc}{\lambda} = 2W + 2eV_0 \qquad ...(ii)$$

Subtracting Eq. (i) from Eq. (ii), we get

$0 = W - eV_0 \Rightarrow W = eV_0$

From Eq. (i),

$$\frac{hc}{\lambda} = eV_0 + 3eV_0 = 4eV_0$$

The threshold wavelength is given by

$$\lambda_{th} = \frac{hc}{W} = \frac{4eV_0\lambda}{eV_0} = 4\lambda$$

08 A photoelectric surface is illuminated successively by monochromatic light of wavelength λ and $\frac{\lambda}{2}$. If the maximum kinetic energy of the emitted photoelectrons in the second case is 3 times that in the first case, the work function of the surface of the material is **[CBSE AIPMT 2015]**

(h = Planck's constant, c = speed of light)

(a) $\frac{hc}{2\lambda}$ (b) $\frac{hc}{\lambda}$ (c) $\frac{2hc}{\lambda}$ (d) $\frac{hc}{3\lambda}$

Ans. *(a)*

According to Einstein's photoelectric equation,

$$E = K_{max} + \phi$$

where, K_{max} is maximum kinetic energy of emitted electron and ϕ is work function of an electron.

$$K_{max} = E - \phi = h\nu - \phi$$

$$K_{max} = \frac{hc}{\lambda} - \phi \qquad ...(i)$$

Similarly, in second case, maximum kinetic energy of emitted electron is 3 times that in first case, we get

$$3K_{max} = \frac{hc}{\frac{\lambda}{2}} - \phi \qquad ...(ii)$$

Solving Eqs. (i) and (ii), we get work function of an emitted electron from a metal surface.

$$\phi = \frac{hc}{2\lambda}$$

09 Light of wavelength 500 nm is incident on a metal with work function 2.28 eV. The de-Broglie wavelength of the emitted electron is **[CBSE AIPMT 2015]**

(a) $< 2.8 \times 10^{-10}$ m (b) $< 2.8 \times 10^{-9}$ m

(c) $\geq 2.8 \times 10^{-9}$ m (d) $\leq 2.8 \times 10^{-12}$ m

Ans. *(c)*

As, energy of photon, $E = h\nu \Rightarrow E = \frac{hc}{\lambda}$

$$\Rightarrow E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}$$

$$\Rightarrow E = \frac{0.0397 \times 10^{-34} \times 10^8}{10^{-9}}$$

$$= 0.0397 \times 10^{-21} \text{ J}$$

$$= \frac{0.0397 \times 10^{-21}}{1.6 \times 10^{-19}} = 0.0248 \times 10^2 \text{ eV}$$

$$= 2.48 \text{ eV}$$

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According to Einstein's photoelectric emission, we have

$$KE_{max} = E - W = 2.48 - 2.28 = 0.2 \text{ eV}$$

For de-Broglie wavelength of the emitted electron,

$$\lambda_{e\,min} = \frac{12.27 \text{ A}}{\sqrt{KE_{max}(eV)}} = \frac{12.27}{\sqrt{0.2}}$$

$$= 27.436 \text{ Å} = 27.436 \times 10^{-10} \text{ m}$$

Thus, minimum wavelength of the emitted electron is

$$\lambda_{min} = 2.7436 \times 10^{-9} \text{ m}$$

i.e. $\lambda \geq \lambda_{min}$

10 When the energy of the incident radiation is increased by 20%, the kinetic energy of the photoelectrons emitted from a metal surface increased from 0.5 eV to 0.8 eV. The work function of the metal is **[CBSE AIPMT 2014]**

(a) 0.65 eV (b) 1.0 eV
(c) 1.3 eV (d) 1.5 eV

Ans. *(b)*

For photo electric equation,

Einstein's equation can be written as

$$(KE)_{max} = h\nu - \phi_0$$

For the first condition,

$$0.5 = E - \phi_0 \quad \ldots(i)$$

For the second condition,

$$0.8 = 1.2E - \phi_0 \quad \ldots(ii)$$

From Eqs. (i) and (ii)

$$-0.3 = -0.2E$$

$$E = \frac{0.3}{0.2} = 1.5 \text{ eV}$$

From Eq. (i) $0.5 = 1.5 - \phi_0$

$$\phi_0 = 0.5 - 0.5 = 1 \text{ eV}$$

11 For photoelectric emission from certain metal, the cut-off frequency is ν. If radiation of frequency 2ν impinges on the metal plate, the maximum possible velocity of the emitted electron will be (m is the electron mass) **[NEET 2013]**

(a) $\sqrt{\frac{h\nu}{(2m)}}$ (b) $\sqrt{\frac{h\nu}{m}}$
(c) $\sqrt{\frac{2h\nu}{m}}$ (d) $2\sqrt{\frac{h\nu}{m}}$

Ans. *(c)*

As we know that,

$$\frac{1}{2}m(v_{max})^2 = h\nu$$

So, $$v_{max} = \sqrt{\frac{2h\nu}{m}}$$

12 Light of two different frequencies whose photons have energies 1 eV and 2.5 eV respectively illuminate a metallic surface whose work function is 0.5 eV successively. Ratio of maximum speeds of emitted electrons will be **[CBSE AIPMT 2011]**

(a) 1 : 2 (b) 1 : 1 (c) 1 : 5 (d) 1 : 4

Ans. *(a)*

Kinetic energy in photoelectric effect can also be written as

$$KE = \phi - \phi_0 \quad \begin{bmatrix} \phi = \text{incident energy} \\ \phi_0 = \text{work function} \end{bmatrix}$$

Given, $KE_1 = 1 - 0.5 = 0.5 \text{ eV}$

$$KE_2 = 2.5 - 0.5 = 2 \text{ eV}$$

So, $$\frac{KE_1}{KE_2} = \frac{0.5}{2} = \frac{1}{4}$$

or $$\frac{v_1^2}{v_2^2} = \frac{1}{4} \quad \left[\because KE = \frac{1}{2}mv^2\right]$$

or $$\frac{v_1}{v_2} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

13 Photoelectric emission occurs only when the incident light has more than a certain minimum **[CBSE AIPMT 2011]**

(a) wavelength (b) intensity
(c) frequency (d) power

Ans. *(c)*

According to the concept of threshold minimum frequency needed for photoelectric emission i.e.

$$KE = h\nu - \phi_0$$

or $$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

So, $$\nu \geq \nu_0$$

14 In photoelectric emission process from a metal of work function 1.8 eV, the kinetic energy of most energetic electrons is 0.5 eV. The corresponding stopping potential is **[CBSE AIPMT 2011]**

(a) 1.3 V (b) 0.5 V
(c) 2.3 V (d) 1.8 V

Ans. *(b)*

As we know that stopping potential gives the maximum KE of ejected electrons, so

$$KE_{max} = eV_0$$

So $6 \times 10^{-19} \times V_0 = 0.5 \times 1.6 \times 10^{-19}$

$\Rightarrow$ $$V_0 = 0.5 \text{ V}$$

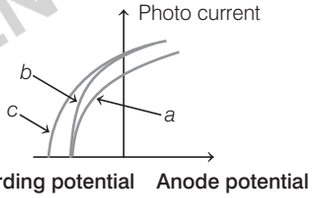
15 The number of photoelectrons emitted for light of a frequency ν (higher than the threshold frequency ν_0) is proportional to **[CBSE AIPMT 2009]**

(a) $\nu - \nu_0$
(b) threshold frequency (ν_0)
(c) intensity of light
(d) frequency of light (ν)

Ans. *(c)*

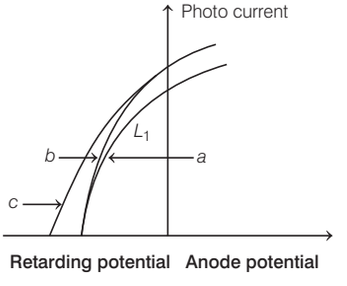
Independent of frequency (ν) of light, it only depends on the intensity of incident light. If intensity increases, number of photo electrons increases.

16 The figure shows a plot of photocurrent *versus* anode potential for a photo sensitive surface for three different radiations. Which one of the following is a correct statement ? **[CBSE AIPMT 2009]**



(a) Curves *a* and *b* represent incident radiations of different frequencies and different intensities
(b) Curves *a* and *b* represent incident radiations of same frequency but of different intensities
(c) Curves *b* and *c* represent incident radiations of different frequencies and different intensities
(d) Curves *b* and *c* represent incident radiations of same frequency having same intensity

Ans. *(b)*



Since in the graph retarding potential is same in graph (a) and (b) and photo current is different so, for curves they have same frequency but different intensity of light.

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17 In the phenomenon of electric discharge through gases at low pressure, the coloured glow in the tube appears as a result of

[CBSE AIPMT 2008]

(a) excitation of electrons in the atoms
(b) collision between the atoms of the gas
(c) collisions between the charged particles emitted from the cathode and the atoms of the gas
(d) collision between different electrons of the atoms of the gas

Ans. *(c)*

In the phenomenon of electric discharge through gases at low pressure, as the charged particles emitted from the cathode collides with the atoms of the gas, coloured glow appears in the tube.

18 The work function of a surface of a photosensitive material is 6.2 eV. The wavelength of the incident radiation for which the stopping potential is 5 V lies in the

[CBSE AIPMT 2008]

(a) ultraviolet region
(b) visible region
(c) infrared region
(d) X-ray region

Ans. *(d)*

According to Einstein's photoelectric equation, kinetic energy of photoelectron

$KE = h\nu - W_0$ or $h\nu = KE + W_0$

As maximum KE of ejected electrons is given by

$KE = eV_0$

where, V_0 is stopping potential.

$h\nu = 5\,eV + 6.2\,eV \quad [\because eV_0 = 5\,eV]$

$= 11.2\,eV$ (lies in X-ray region)

19 A 5 W source emits monochromatic light of wavelength 5000 Å. When placed 0.5 m away, it liberates photoelectrons from a photosensitive metallic surface. When the source is moved to a distance of 1.0 m, the number of photoelectrons liberated will be reduced by a factor of

[CBSE AIPMT 2007]

(a) 4 (b) 8
(c) 16 (d) 2

Ans. *(a)*

Intensity of light is inversely proportional to square of distance of source

i.e. $I \propto \frac{1}{d^2}$

For two different situations, $\frac{I_2}{I_1} = \frac{(d_1)^2}{(d_2)^2}$

Given, $d_1 = 0.5$ m, $d_2 = 1.0$ m

Therefore, $\frac{I_2}{I_1} = \frac{(0.5)^2}{(1)^2} = \frac{1}{4}$

Since, number of photoelectrons emitted per second is directly proportional to intensity, so number of electrons emitted would decrease by factor of 4.

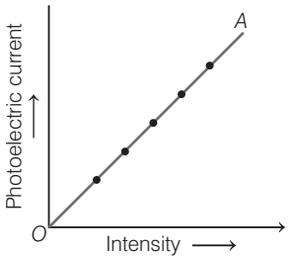
20 A photocell employs photoelectric effect to convert

[CBSE AIPMT 2006]

(a) change in the frequency of light into a change in electric voltage
(b) change in the intensity of illumination into a change in photoelectric current
(c) change in the intensity of illumination into a change in the work function of the photocathode
(d) change in the frequency of light into a change in the electric current

Ans. *(b)*

In a photoelectric effect, when monochromatic radiations of suitable frequency fall on the photosensitive plate called cathode, the photoelectrons are emitted which get accelerated towards anode. These electrons flow in the outer circuit resulting in the photoelectric current.



Using the incident radiations of a fixed frequency, it is found that the photoelectric current increases linearly with the intensity of incident light as shown in figure. Hence, a photocell employs photoelectric effect to convert change in the intensity of illumination into a change in photoelectric current.

21 A photosensitive metallic surface has work function, $h\nu_0$. If photons of energy $2h\nu_0$ fall on this surface, the electrons come out with a maximum velocity of 4×10^6 m/s. When the photon energy is increased to $5h\nu_0$, then maximum velocity of photoelectrons will be

[CBSE AIPMT 2005]

(a) 2×10^6 m/s (b) 2×10^7 m/s
(c) 8×10^5 m/s (d) 8×10^6 m/s

Ans. *(d)*

Einstein's photoelectric equation can be written as

$$KE = \frac{1}{2}mv^2 = h\nu - W_0$$

where, [W_0 = work function]

When photon of energy $2h\nu_0$ falls then

$$\Rightarrow \frac{1}{2}m \times (4 \times 10^6)^2 = 2h\nu_0 - h\nu_0 \quad ...(i)$$

When photon of energy $5h\nu_0$ falls then

$$\frac{1}{2}m \times v^2 = 5h\nu_0 - h\nu_0 \quad ...(ii)$$

Dividing Eq. (i) by (ii), we get

$$\frac{v^2}{(4 \times 10^6)^2} = \frac{4h\nu_0}{h\nu_0}$$

or $v^2 = 4 \times 16 \times 10^{12}$

or $v^2 = 64 \times 10^{12}$

$\therefore v = 8 \times 10^6$ m/s

22 The work functions for metals *A*, *B* and *C* are respectively 1.92 eV, 2.0 eV and 5 eV. According to Einstein's equation, the metals which will emit photoelectrons for a radiation of wavelength 4100 Å is/are

[CBSE AIPMT 2005]

(a) None of these
(b) *A* only
(c) *A* and *B* only
(d) All the three metals

Ans. *(c)*

Work function for wavelength of 4100 Å is given by

$$W_0 = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{4100 \times 10^{-10}}$$

$= 4.8 \times 10^{-19}$ J

Energy in eV is given by

$$= \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}}\,eV = 3\,eV$$

Now, we have

$W_A = 1.92$ eV,

$W_B = 2.0$ eV,

$W_C = 5$ eV

Since, $W_A < W$

and $W_B < W$, hence, *A* and *B* will emit photoelectrons.

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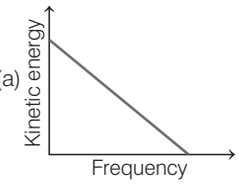
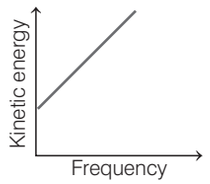
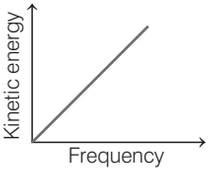
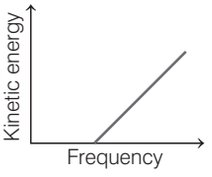
23 According to Einstein's photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is **[CBSE AIPMT 2004]**

(a) 

(b) 

(c) 

(d) 

Ans. ***(d)***

Einstein's photoelectric equation is

$$KE = h\nu - W_0 \quad \text{...(i)}$$

where, W_0 = work function of metal, $(= h\nu_0)$

Comparing above Eq. (i) with equation of a straight line $y = mx + c$

we get, $m = h$, $c = -W_0$

Therefore, if we draw a graph between kinetic energy and frequency, then a straight line cutting the frequency axis at ν_0 and giving an intercept of $(-W_0)$ on the kinetic energy axis, is obtained.

NOTE

As we know that for emission of electrons, there is a certain threshold frequency after which emission starts. Considering this fact graph (*d*) is correct.

24 A photoelectric cell is illuminated by a point source of light 1 m away. When the source is shifted to 2 m, then **[CBSE AIPMT 2003]**

(a) each emitted electron carries half the initial energy

(b) number of electrons emitted is a quarter of the initial number

(c) each emitted electron carries one quarter of the initial energy

(d) number of electrons emitted is half the initial number

Ans. ***(b)***

Intensity of light source is inversely proportional to the distance (d)

i.e. $I \propto \frac{1}{d^2}$

When distance is doubled, intensity becomes one-fourth. As number of photoelectrons $\propto$ intensity, so number of photoelectrons is quarter of the initial number.

25 When ultraviolet rays are incident on metal plate, the photoelectric effect does not occur. It occurs by incidence of **[CBSE AIPMT 2002]**

(a) infrared rays (b) X-rays

(c) radiowaves (d) light waves

Ans. ***(b)***

For photoelectric emission from given metal plate, the incident wavelength must be less than that of ultraviolet rays assuming the wavelength of ultraviolet rays as the threshold value. Out of the given radiations, X-rays have wavelength less than that of ultraviolet rays. Thus, X-rays can cause photoelectric emission.

26 Which of the following is not the property of cathode rays? **[CBSE AIPMT 2002]**

(a) It produces heating effect

(b) It does not deflect in electric field

(c) Its casts shadow

(d) It produces fluorescence

Ans. ***(b)***

Cathode rays are negatively charged particles called as electrons

(a) Cathode rays possess very high kinetic energy due to their high velocity. When these highly energetic rays fall on platinum (a metal), their kinetic energy is converted to heat energy.

(b) Outside the discharge tube, if an electric field is applied, the cathode rays bend towards the positive plate.

(c) Cathode rays travel in straight lines. This can be proved by an arrangement which shows that cathode rays cast shadow of the object placed in straight line path of cathode rays.

(d) In certain substances like barium platinocyanides, zinc sulphate, diamond etc, they produce fluorescence.

Thus, (b) is right option.

27 A light source is at a distance d from a photoelectric cell, then the number of photoelectrons emitted from the cell is n. If the distance of light source and cell is reduced to half, then the number of photoelectrons emitted will become **[CBSE AIPMT 2001]**

(a) $\frac{n}{2}$ (b) $2n$ (c) $4n$ (d) n

Ans. ***(c)***

Intensity of light source is given by

$$I \propto \frac{1}{d^2}$$

where, d is the distance of light source from the cell.

So, for two different situations for intensities,

$$\text{or } \frac{I_1}{I_2} = \left(\frac{d_2}{d_1}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

$$\text{or } I_2 = 4I_1$$

As number of photoelectrons emitted is directly proportional to intensity, so number of photoelectrons emitted will become 4 times, i.e. $4n$.

28 Einstein's work on photoelectric effect gives support to **[CBSE AIPMT 2000]**

(a) $E = mc^2$ (b) $E = h\nu$

(c) $h\nu = \frac{1}{2}mv^2$ (d) $E = \frac{h}{\lambda}$

Ans. ***(b)***

In 1905, Einstein realized that the photoelectric effect could be understood if the energy in light is not spread out over wavefronts but is concentrated in small packets, or photons. Each photon of light of frequency ν has the energy $h\nu$. Thus, Einstein's work on photoelectric effect gives support to $E = h\nu$.

29 When intensity of incident light increases **[CBSE AIPMT 1999]**

(a) photocurrent increases

(b) photocurrent decreases

(c) kinetic energy of emitted photoelectrons increases

(d) kinetic energy of emitted photoelectrons decreases

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Ans. *(a)*

According to Einstein's theory of photoelectric effect, a single incident photon ejects a single electron. Therefore, when intensity increases, the number of incident photons increases, so number of ejected electrons increases, hence, photocurrent increases.

Now, maximum energy of electron $= \frac{1}{2} mv_{max}^2$ and $\frac{1}{2} mv_{max}^2 = eV_0$, where V_0 is stopping potential.

Thus, the maximum kinetic energy of the electrons does not depend upon the intensity of the incident rays, because the stopping potential is not affected by the increase of the intensity of rays. Hence, options (c) and (d) are wrong.

30 The photoelectric work function for a metal surface is 4.125 eV. The cut-off wavelength for this surface is **[CBSE AIPMT 1999]**

(a) 4125 Å (b) 3000 Å
(c) 6000 Å (d) 2062.5 Å

Ans. *(b)*

The minimum wavelength below which no photoelectron can emit from metal surface is called cut-off wavelength or threshold wavelength and is given by

$$\text{Work function} = \frac{hc}{\text{cut - off wavelength}}$$

or $$\text{cut-off wavelength} = \frac{hc}{\text{work function}}$$

$$\therefore \quad \lambda_0 = \frac{hc}{W_0} \qquad ...(i)$$

Given, $h = 6.6 \times 10^{-34}$ J-s

$c = 3 \times 10^8$ m/s

$W_0 = 4.125$ eV

$= 4.125 \times 1.6 \times 10^{-19}$ J

Substituting the given values in Eq. (i), we get

$$\lambda_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.125 \times 1.6 \times 10^{-19}} \text{ Å}$$

$$= 3 \times 10^{-7} \text{ m} = 3000 \text{ Å}$$

31 In a photoemissive cell, with exciting wavelength λ, the fastest electron has speed v. If the exciting wavelength is changed to $3\lambda/4$, the speed of the fastest emitted electron will be **[CBSE AIPMT 1998]**

(a) $v\left(\frac{3}{4}\right)^{1/2}$

(b) $v\left(\frac{4}{3}\right)^{1/2}$

(c) less than $v\left(\frac{4}{3}\right)^{1/2}$

(d) greater than $v\left(\frac{4}{3}\right)^{1/2}$

Ans. *(d)*

Einstein's photoelectric equation is given by

$$\text{KE} = E - W_0$$

As we know that

$$\text{KE} = \frac{1}{2} mv^2$$

and $$E = \frac{hc}{\lambda}$$

$$\therefore \quad \frac{1}{2} mv^2 = \frac{hc}{\lambda} - W_0 \qquad ...(i)$$

Suppose v' be the new speed, when λ is changed to $\frac{3\lambda}{4}$.

The new equation can be written as

$$\frac{1}{2} mv'^2 = \frac{hc}{(3\lambda/4)} - W_0$$

or $$\frac{1}{2} mv'^2 = \frac{4}{3}\frac{hc}{\lambda} - W_0 \qquad ...(ii)$$

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{v'^2}{v^2} = \frac{\frac{4}{3}\frac{hc}{\lambda} - W_0}{\frac{hc}{\lambda} - W_0} = \frac{\frac{4}{3}\frac{hc}{\lambda} - \frac{4}{3}W_0 + \frac{1}{3}W_0}{\frac{hc}{\lambda} - W_0} = \frac{4}{3} + \frac{W_0}{3\left(\frac{hc}{\lambda} - W_0\right)} > \frac{4}{3}$$

$$\therefore \quad \frac{v'}{v} > \sqrt{\frac{4}{3}} \quad \text{or} \quad v' > \sqrt{\frac{4}{3}} v$$

32 Light of wavelength 5000 Å falls on a sensitive plate with photoelectric work function of 1.9 eV. The kinetic energy of the photoelectron emitted will be **[CBSE AIPMT 1998]**

(a) 0.58 eV (b) 2.48 eV
(c) 1.24 eV (d) 1.16 eV

Ans. *(a)*

Energy of photon is given by

$$E = \frac{hc}{\lambda} = \frac{12375}{\lambda(\text{Å})} \text{ eV}$$

$$[\because hc = 12375 \text{ eV- Å}]$$

$$\therefore \quad E = \frac{12375}{5000} = 2.48 \text{ eV}$$

According to Einstein's photoelectric equation

$$\text{KE} = E - W_0 = 2.48 \text{eV} - 1.9 \text{eV}$$

$$= 0.58 \text{ eV}$$

33 Which of the following is true ? **[CBSE AIPMT 1997]**

(a) The stopping potential increases with increasing intensity of incident light
(b) The photocurrent increases with increasing intensity of light
(c) The current in photocell increases with increasing frequency of light
(d) The photocurrent is proportional to applied voltage

Ans. *(b)*

(a) Stopping potential is the negative potential applied to stop the photoelectrons from the metal. Stopping potential is given by

$$eV_0 = K_{max}$$

Since, maximum kinetic energy of photo- electrons does not depend on intensity of light, so stopping potential does not vary with intensity of light. Thus, choice (a) is not correct.

(b) If intensity of incident light is increased, we can say that the number of photons incident per unit area per unit time will be increased. Therefore, more electrons will be emitted per second. Hence, photo-current increases. Thus, choice (b) is correct.

(c) The photo-current does not depend on frequency of light. Thus, choice (c) is not correct.

(d) The photo-current does not depend on applied voltage. Thus, choice (d) is not correct.

34 If the threshold wavelength for a certain metal is 2000 Å, then the work function of the metal is **[CBSE AIPMT 1995]**

(a) 6.2 J (b) 6.2 eV
(c) 6.2 MeV (d) 6.2 keV

Ans. *(b)*

The minimum energy required to remove an electron from the surface of metal without giving any kinetic energy is called work function.

$$W_0 = h\nu_0 = \frac{hc}{\lambda_0}$$

Given wavelength,

$$\lambda_0 = 2000 \text{ Å} = 2000 \times 10^{-10} \text{ m}$$

$$\therefore \quad W_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2000 \times 10^{-10}}$$

$$= 9.9 \times 10^{-19} \text{ J} = \frac{9.9 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$[1 \text{eV} = 1.6 \times 10^{-19} \text{ J}]$$

$$= 6.2 \text{ eV}$$

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35 In photoelectric effect, the work function of a metal is 3.5 eV. The emitted electrons can be stopped by applying a potential of – 1.2 V. Then, **[CBSE AIPMT 1994]**

(a) the energy of the incident photons is 4.7 eV
(b) the energy of the incident photons is 2.3 eV
(c) if higher frequency photons be used, the photoelectric current will rise
(d) when the energy of photons is 3.5 eV, the photoelectric current will be maximum

Ans. *(a)*

When a photon of light of frequency ν is incident on a photosensitive metal surface. Then, according to Einstein's photoelectric equation

$$h\nu = W_0 + \frac{1}{2}mv^2$$

where, W_0 is work function of the metal and $\frac{1}{2}mv^2$ is KE of the photoelectron.

Given, $W_0 = 3.5\,\text{eV}$, $\text{KE} = 1.2\,\text{eV}$

$\therefore\ h\nu = 3.5 + 1.2 = 4.7\,\text{eV}$

Note

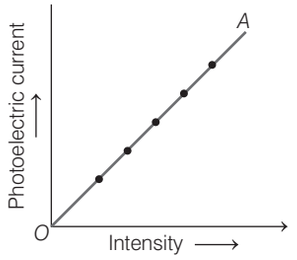
Stopping potential always gives maximum kinetic energy of ejected electrons.

36 Number of ejected photoelectron increases with increase **[CBSE AIPMT 1993]**

(a) in intensity of light
(b) in wavelength of light
(c) in frequency of light
(d) Never

Ans. *(a)*

It is found that the photoelectric current increases linearly with the intensity of incident light.



It means number of photoelectrons emitted per second from photosensitive plate is directly proportional to the intensity of the incident radiation.

37 The cathode of a photoelectric cell is changed such that the work function changes from W_1 to W_2 ($W_2 > W_1$). If the current before and after changes are I_1 and I_2, all other conditions remaining unchanged, then (assuming $h\nu > W_2$) **[CBSE AIPMT 1992]**

(a) $I_1 = I_2$ (b) $I_1 < I_2$
(c) $I_1 > I_2$ (d) $I_1 < I_2 < 2I_1$

Ans. *(a)*

By work function of a metal, it means that the minimum energy required for the electron in the highest level of conduction band to get out of the metal. The work function has no effect on photoelectric current as long as $h\nu > W_0$. The photoelectric current is proportional to the intensity of incident light. Since, there is no change in the intensity of light, hence $I_1 = I_2$

38 Photoelectric work function of a metal is 1 eV, light of wavelength $\lambda = 3000$ Å falls on it. The photoelectrons come out with velocity **[CBSE AIPMT 1991]**

(a) 10 m/s (b) 10^2 m/s
(c) 10^4 m/s (d) 10^6 m/s

Ans. *(d)*

According to Einstein's photoelectric equation, KE of the photoelectron

$$\frac{1}{2}mv^2 = \frac{hc}{\lambda} - W_0$$

$$\left[\begin{array}{l}\text{where, } W_0 = \text{work function} \\ \frac{1}{2}mv^2 = \text{KE of ejected electrons} \\ \frac{hc}{l} = \text{threshold energy}\end{array}\right]$$

Given, $\lambda = 3000\ \text{Å} = 3000 \times 10^{-10}$ m

$W_0 = 1\,\text{eV} = 1.6 \times 10^{-19}$ J

$m = 9.1 \times 10^{-31}$ kg

$\therefore\ \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{3000 \times 10^{-10}} - 1.6 \times 10^{-19}$$

$\Rightarrow\ v = 10^6$ m/s

39 Ultraviolet radiation of 6.2 eV falls on an aluminium surface. KE of fastest electron emitted is (work function = 4.2 eV) **[CBSE AIPMT 1989]**

(a) 3.2×10^{-21} J (b) 3.2×10^{-19} J
(c) 7×10^{-25} J (d) 9×10^{-32} J

Ans. *(b)*

According to Einstein photoelectric equation

$$\text{KE} = E - W_0$$

$$\left[\begin{array}{l}E = \text{energy incidented} \\ W_0 = \text{work function}\end{array}\right]$$

Here, $E = 6.2\,\text{eV}$

$W_0 = 4.2\,\text{eV}$

$\therefore\ \text{KE} = 6.2 - 4.2 = 2.0\,\text{eV}$

$= 2 \times 1.6 \times 10^{-19}$

$= 3.2 \times 10^{-19}$ J

40 The threshold frequency for photoelectric effect on sodium corresponds to a wavelength of 5000 Å. Its work function is **[CBSE AIPMT 1988]**

(a) 4×10^{-19} J
(b) 1 J
(c) 2×10^{-19} J
(d) 3×10^{-19} J

Ans. *(a)*

When a photon of light of frequency ν incident on a photosensitive metal surface, the energy of the photon ($h\nu$) is spent in two ways. A part of energy of photon is used in liberating the electron from the metal surface which is equal to the work function W_0 of the metal.

$$W_0 = h\nu_0$$

(where, ν_0 is threshold frequency)

or $W_0 = \frac{hc}{\lambda_0}$

Here, $\lambda_0 = 5000\ \text{Å}$

$= 5000 \times 10^{-10}$ m

$\therefore\ W_0 = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{5000 \times 10^{-10}}$

$= 4 \times 10^{-19}$ J

Threshold frequency (ν_0) → It is the minimum frequency given to metallic surface so that emission of electrons start.

41 Which of the following are thermions ? **[CBSE AIPMT 1988]**

(a) Protons (b) Electrons
(c) Photons (d) Positrons

Ans. *(b)*

Thermionic emission is the phenomenon of emission of electrons from the metal surface when heated suitably. Here, the energy required for the emission of electrons from metal surface is being supplied by thermal energy. The emitted electrons are called thermal electrons or thermions.

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TOPIC 2
Particle Nature of Light– The Photon

42 The number of photons per second on an average emitted by the source of monochromatic light of wavelength 600 nm, when it delivers the power of 3.3×10^{-3} W will be ($h=6.6\times10^{-34}$ J-s) **[NEET 2021]**

(a) 10^{18} (b) 10^{17} (c) 10^{16} (d) 10^{15}

Ans. *(c)*

Given, the monochromatic light of the wavelength, $\lambda=600\ \text{nm}$

The power of the source,

$P=3.3\times10^{-3}$ W

We know that, $P=\dfrac{nhc}{\lambda}$

Here, P is the power of the source,

n is the number of photons per second,

h is the Planck's constant,

c is the speed of the light in vacuum,

λ is the wavelength of the monochromatic light.

Substituting the values in the above equation, we get

$$3.3\times10^{-3}=\frac{n\times6.6\times10^{-34}\times3\times10^{8}}{600\times10^{-9}}$$

$$\Rightarrow\quad n=10^{16}$$

43 A 200 W sodium street lamp emits yellow light of wavelength 0.6 μm. Assuming it to be 25% efficient in converting electrical energy to light, the number of photons of yellow light it emits per second is **[CBSE AIPMT 2012]**

(a) 1.5×10^{20}

(b) 6×10^{18}

(c) 62×10^{20}

(d) 3×10^{19}

Ans. *(a)*

Efficient power (P) is given by

$$P=\frac{N}{t}\times\frac{hc}{\lambda}$$

(N = total number of photons)

$$\frac{N}{t}=\frac{P\times\lambda}{hc}$$

$$=\frac{50\times0.6\times10^{-6}}{6.6\times10^{-34}\times3\times10^{8}}$$

$[\because=25\%\text{ of }200\text{W}=50\text{W}]$

$$=1.5\times10^{20}$$

44 A source S_1 is producing, 10^{15} photons/s of wavelength 5000 Å. Another source S_2 is producing 1.02×10^{15} photons per second of wavelength 5100 Å. Then, (power of S_2)/ (power of S_1) is equal to **[CBSE AIPMT 2010]**

(a) 1.00 (b) 1.02

(c) 1.04 (d) 0.98

Ans. *(a)*

Number of photons emitted per second is given by

$$n=\frac{P}{\left(\frac{hc}{\lambda}\right)}\qquad\left[\begin{array}{l}P=\text{Power}\\ \frac{hc}{\lambda}=\text{Energy}\end{array}\right]$$

So, $P=\dfrac{nhc}{\lambda}$

So, for two different situations,

$$\Rightarrow\quad\frac{P_2}{P_1}=\frac{n_2\lambda_1}{n_1\lambda_2}=\frac{1.02\times10^{15}\times5000}{10^{15}\times5100}=1$$

45 Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is **[CBSE AIPMT 2009]**

(a) 9×10^{17} (b) 3×10^{16}

(c) 9×10^{15} (d) 3×10^{19}

Ans. *(b)*

Here, $\lambda=667\times10^{-9}$ m, $P=9\times10^{-3}$ W

$$\text{Power}=\frac{\text{energy}\,(E)}{\text{time}\,(t)}$$

$$=\frac{nhc}{\lambda t}=\frac{Nhc}{\lambda}$$

$$\left[\begin{array}{l}E=\dfrac{hc}{\lambda},\ n=\text{Total number of photons}\\ N=\text{Number of photons emitted}\\ \text{per second}=\dfrac{n}{t}\end{array}\right]$$

$$\text{So, }N=\frac{P\times\lambda}{hc}=\frac{9\times10^{-3}\times667\times10^{-9}}{6.6\times10^{-34}\times3\times10^{8}}$$

$$=3\times10^{16}\ \text{m/s}$$

46 Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2×10^{-3} W. The number of photons emitted, on the average, by the source per second is **[CBSE AIPMT 2007]**

(a) 5×10^{15} (b) 5×10^{16}

(c) 5×10^{17} (d) 5×10^{14}

Ans. *(a)*

Power emitted, $P=2\times10^{-3}$ W

Energy of photon,

$$E=h\nu=6.6\times10^{-34}\times6\times10^{14}\ \text{J}$$

Here, h being Planck's constant.

Number of photons emitted per second is given by

$$n=\frac{\text{Power}\,(P)}{\text{Energy}\,(E)}$$

$$=\frac{2\times10^{-3}}{6.6\times10^{-34}\times6\times10^{14}}=5\times10^{15}$$

47 The momentum of a photon of energy 1 MeV in kg m/s, will be **[CBSE AIPMT 2006]**

(a) 0.33×10^{6} (b) 7×10^{-24}

(c) 10^{-22} (d) 5×10^{-22}

Ans. *(d)*

Energy of photon is given by

$$E=\frac{hc}{\lambda}\qquad\ldots(i)$$

where h is Planck's constant, c the velocity of light and λ its wavelength.

de-Broglie wavelength is given by

$$\lambda=\frac{h}{p}\qquad\ldots(ii)$$

p being momentum of photon.

From Eqs. (i) and (ii), we have

$$E=\frac{hc}{h/p}=pc\ \text{ or }\ p=\frac{E}{c}$$

Given, $E=1\text{MeV}=1\times10^{6}\times1.6\times10^{-19}$ J,

$1\text{eV}=1.6\times10^{19}$ J

$c=3\times10^{8}$ m/s

Hence, after putting numerical values, we obtain

$$p=\frac{1\times10^{6}\times1.6\times10^{-19}}{3\times10^{8}}\ \text{kg-m/s}$$

$$=5\times10^{-22}\ \text{kg-m/s}$$

48 The 21 cm radiowave emitted by hydrogen in interstelar space is due to the interaction called the hyperfine interaction in atomic hydrogen. The energy of the emitted wave is nearly **[CBSE AIPMT 1998]**

(a) 10^{-17} J (b) 1 J

(c) 7×10^{-6} J (d) 10^{-24} J

Ans. *(d)*

The energy of emitted photon is given by

$$E=\frac{hc}{\lambda}$$

Given, wavelength, $\lambda=21\,\text{cm}=0.21\,\text{m}$

$$\text{So, }E=\frac{6.6\times10^{-34}\times3\times10^{8}}{0.21}=10^{-24}\ \text{J}$$

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49 The nature of ions knocked out from hot surfaces is **[CBSE AIPMT 1995]**

(a) protons (b) electrons
(c) neutrons (d) nuclei

Ans. *(b)*

In thermionic emission and other types of emission, ions emitted are atoms that has lost or gained electrons having negative or positive charge respectively. Thus, the nature of ions knocked out from hot surfaces, are electrons.

50 Momentum of a photon of wavelength λ is **[CBSE AIPMT 1993]**

(a) $\frac{h}{\lambda}$ (b) zero (c) $\frac{h\lambda}{c^2}$ (d) $\frac{h\lambda}{c}$

Ans. *(a)*

As a photon moves with the velocity of light

i.e. $v = c$

$\therefore$ The momentum of the photon

$$= mc = \frac{h\nu}{c} = \frac{h}{\lambda} \qquad \left[\lambda = \frac{c}{\nu}\right]$$

51 The wavelength of a 1 keV photon is 1.24×10^{-9} m. What is the frequency of 1 MeV photon? **[CBSE AIPMT 1991]**

(a) 1.24×10^{15} Hz (b) 2.4×10^{20} Hz
(c) 1.24×10^{18} Hz (d) 2.4×10^{23} Hz

Ans. *(b)*

Energy of photon is $E = h\nu = \frac{hc}{\lambda}$

As, $\frac{hc}{\lambda} = 10^3$ eV

$\therefore$ $h = \frac{10^3 \lambda}{c}$ ...(i)

And for 2nd case as given in question

$h\nu = 10^6$ eV ...(ii)

Putting value of h in Eq. (ii),

$$\frac{10^3 \lambda}{c}\nu = 10^6$$

$\therefore$ $$\nu = \frac{10^3 c}{\lambda}$$

$$= \frac{10^3 \times 3 \times 10^8}{1.24 \times 10^{-9}} \qquad [\because \lambda = 1.24 \times 10^{-9}\,\text{m}]$$

$$= 2.4 \times 10^{20} \text{ Hz}$$

52 The momentum of a photon of an electro- magnetic radiation is 3.3×10^{-29} kg-ms^{-1}. What is the frequency of the associated waves? **[CBSE AIPMT 1990]**

($h = 6.6 \times 10^{-34}$ J-s, $c = 3 \times 10^8$ ms^{-1})

(a) 1.5×10^{13} Hz (b) 7.5×10^{12} Hz
(c) 6.0×10^{13} Hz (d) 3.0×10^3 Hz

Ans. *(a)*

The energy of a photon of a radiation of frequency ν and wavelength λ is

$$E = h\nu = \frac{hc}{\lambda} \qquad ...(i)$$

If photon is considered to be a particle of mass m, the energy associated with it, according to Einstein mass energy relation, is given by

$$E = mc^2 \qquad ...(ii)$$

From Eqs. (i) and (ii),

$$h\nu = mc^2$$

or $$m = \frac{h\nu}{c^2} \Rightarrow \frac{h\nu}{c} = mc$$

As $mc = p$

(p = momentum of photon)

So, $$\nu = \frac{cp}{h} = \frac{3 \times 10^8 \times 3.3 \times 10^{-29}}{6.6 \times 10^{-34}}$$

$$= 1.5 \times 10^{13} \text{ Hz}$$

53 A radio transmitter operates at a frequency 880 kHz and a power of 10 kW. The number of photons emitted per second is **[CBSE AIPMT 1990]**

(a) 1.72×10^{31} (b) 1.327×10^{25}
(c) 1.327×10^{37} (d) 1.327×10^{45}

Ans. *(a)*

Power of radio transmitter = 10 kW

$$= 10000 \text{ W}$$

Operating frequency of transmitter

$$= 880 \text{ kHz} = 880 \times 10^3 \text{ Hz}$$

Number of photons emitted per second

$$n = \frac{P}{E} = \frac{P}{h\nu}$$

$$= \frac{10^4}{6.63 \times 10^{-34} \times 880 \times 10^3} \qquad [h = 6.63 \times 10^{-34}\text{J-s}]$$

$$= 1.72 \times 10^{31}$$

54 The energy of a photon of wavelength λ is **[CBSE AIPMT 1988]**

(a) $hc\lambda$ (b) $\frac{hc}{\lambda}$ (c) $\frac{\lambda}{hc}$ (d) $\frac{\lambda h}{c}$

Ans. *(b)*

According to Planck's quantum theory, a source of radiation emits energy in the form of photons, which travel in straight line. The energy of a photon is given by

$$E = h\nu = \frac{hc}{\lambda}$$

where, h = Planck's constant

$$= 6.62 \times 10^{-34} \text{ J-s}$$

ν, and λ = frequency and wavelength of photon, respectively

and c = speed of light

$$= 3 \times 10^8 \text{ m/s}$$

TOPIC 3
Wave Nature of Light

55 The de-Broglie wavelength of an electron moving with kinetic energy of 144 eV is nearly **[NEET (Oct.) 2020]**

(a) 102×10^{-3} nm (b) 102×10^{-4} nm
(c) 102×10^{-5} nm (d) 102×10^{-2} nm

Ans. *(d)*

Kinetic energy of electron,

$K = 144$ eV $\Rightarrow$ $eV = 144$ eV

$\Rightarrow$ $V = 144$ V

$\therefore$ de-Broglie wavelength

$$\lambda = \frac{1.227}{\sqrt{V}}\text{Å} = \frac{1.227}{\sqrt{144}}\text{Å} = \frac{1.227}{12}\text{Å}$$

$$= 0.102\text{Å} = 1.02\,\text{nm}$$

$$= 102 \times 10^{-2}\,\text{nm}$$

56 The wave nature of electrons was experimentally verified by **[NEET (Oct.) 2020]**

(a) de-Broglie
(b) Hertz
(c) Einstein
(d) Davisson and Germer

Ans. *(a)*

The wave nature of electrons was experimentally verified by de-Broglie.

57 An electron is accelerated from rest through a potential difference of V volt. If the de-Broglie wavelength of the electron is 1.227×10^{-2} nm, the potential difference is **[NEET (Sep.) 2020]**

(a) 10^2 V (b) 10^3 V (c) 10^4 V (d) 10 V

Ans. *(c)*

Given, $\lambda = 1.227 \times 10^{-2}$ nm $= 1.227 \times 10^{-11}$ m

Potential difference, V = ?

Relation for de-Broglie wavelength for moving electron is

$$\lambda = \frac{12.27}{\sqrt{V}}\text{Å}$$

$\Rightarrow$ $$\sqrt{V} = \frac{12.27}{\lambda} \times 10^{-10}$$

$$= \frac{12.27 \times 10^{-10}}{1.227 \times 10^{-11}} = 10^2$$

$\Rightarrow$ $V = 10^4$ V

Hence, correct option is (c).

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58 A proton and an α-particle are accelerated from rest to the same energy. The de-Broglie wavelengths λ_p and λ_α are in the ratio **[NEET (Odisha) 2019]**

(a) 2 : 1 (b) 1 : 1 (c) $\sqrt{2}$: 1 (d) 4 : 1

Ans. *(a)*

The de-Broglie wavelength associated with a charged particle is given by

$$\lambda = \frac{h}{p}$$

where, h = planck's constant and p = momentum = $\sqrt{2mKE}$ (here, KE is the kinetic energy of the charged particle)

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2m\text{KE}}}$$

For proton and α-particle, the wavelengths are respectively given as,

$$\lambda_p = \frac{h}{\sqrt{2m_p\text{KE}_p}}$$

and $$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha\text{KE}_\alpha}}$$

$$\therefore \quad \frac{\lambda_p}{\lambda_\alpha} = \frac{\sqrt{2m_\alpha\text{KE}_\alpha}}{\sqrt{2m_P\text{KE}_P}} \qquad ...(i)$$

Here, $KE_\alpha = KE_P$ and $m_\alpha = 4m_p$

Substituting these above mentioned relations in Eq. (i), we get

$$\Rightarrow \quad \frac{\lambda_P}{\lambda_\alpha} = \sqrt{\frac{4m_P}{m_p}} = \frac{2}{1}$$

or $$\lambda_P : \lambda_\alpha = 2 : 1$$

59 An electron is accelerated through a potential difference of 10,000 V. Its de-Broglie wavelength is, (nearly) : ($m_e = 9 \times 10^{-31}$ kg) **[NEET (National) 2019]**

(a) 12.2×10^{-12} m (b) 12.2×10^{-14} m
(c) 12.2 nm (d) 12.2×10^{-13} m

Ans. *(a)*

Given, potential difference, V = 10000 V

If electron is accelerated through a potential of V volt, then the wavelength associated with it is given by

$$\lambda = \frac{h}{\sqrt{2eVm_e}} \qquad ... (i)$$

where, h = Planck's constant = 6.63×10^{-34} J-s,

e = electronic charge = 1.6×10^{-19} C

and m_e = mass of electron = 9×10^{-31} kg

Substituting these values in Eq. (i), we get

$$\lambda = \frac{12.27}{\sqrt{V}}\text{Å} = \frac{12.27}{\sqrt{10000}} \times 10^{-10}$$

$$= \frac{12.27 \times 10^{-10}}{100} = 12.27 \times 10^{-12} \text{ m}$$

60 An electron of mass m with a velocity $\mathbf{v} = v_0\hat{\mathbf{i}}$ ($v_0 > 0$) enters an electric field $\mathbf{E} = -E_0\hat{\mathbf{i}}$ (E_0 = constant > 0) at $t = 0$. If λ_0 is its de-Broglie wavelength initially, then its de-Broglie wavelength at time t is **[NEET 2018]**

(a) $\lambda_0 t$ (b) $\lambda_0\left(1 + \frac{eE_0}{mv_0}t\right)$

(c) $\frac{\lambda_0}{\left(1 + \frac{eE_0}{mv_0}t\right)}$ (d) λ_0

Ans. *(c)*

According to the question,

$\mathbf{v} = v_0\hat{\mathbf{i}}$, $\mathbf{E} = -E_0\hat{\mathbf{i}}$

$E_0 \longleftarrow$

$F \longleftarrow \bigcirc \longrightarrow E_0$

m

Thus, magnitude of force on the electron due to the electric field, $|\mathbf{F}| = q|\mathbf{E}|$

$$\Rightarrow \quad F = eE_0$$

From Newton's second law of motion,

$$F = ma$$

$$\therefore \quad F = ma = eE_0$$

$$\Rightarrow \quad a = \frac{eE_0}{m} \qquad ...(i)$$

or $$\mathbf{a} = \frac{(-e)(-E_0\hat{\mathbf{i}})}{m} = \frac{eE_0}{m}\hat{\mathbf{i}}$$

From first equation of motion,

$$v = u + at$$

Here, u (initial velocity) = v_0

$$\Rightarrow \quad v = v_0 + \frac{eE_0}{m}t \quad ...(ii) \text{(from Eq. (i))}$$

Initial de-Broglie wavelength of the electron is given as

$$\lambda_0 = \frac{h}{mv_0} \Rightarrow h = \lambda mv_0 \qquad ...(iii)$$

After time t, de-Broglie wavelength is given as

$$\lambda = \frac{h}{mv}$$

Substituting the value of v from Eq. (ii), we get

$$\lambda = \frac{h}{m\left(v_0 + \frac{eE_0}{m}t\right)}$$

$$= \frac{h}{mv_0\left[1 + \frac{eE_0}{mv_0}t\right]}$$

$$= \frac{\lambda mv_0}{mv_0\left[1 + \frac{eE_0}{mv_0}t\right]} \qquad \text{[from Eq. (iii)]}$$

$$= \frac{\lambda_0}{\left[1 + \frac{eE_0}{mv_0}t\right]}$$

$$\therefore \quad \lambda = \frac{\lambda_0}{1 + \frac{eE_0}{mv_0}t}$$

61 The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (Kelvin) and mass m, is **[NEET 2017]**

(a) $\frac{h}{\sqrt{mkT}}$ (b) $\frac{h}{\sqrt{3mkT}}$

(c) $\frac{2h}{\sqrt{3mkT}}$ (d) $\frac{2h}{\sqrt{mkT}}$

Ans. *(b)*

Thinking Process de-Broglie wavelength associated with a moving particle can be given as

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m((\text{KE})}}$$

At thermal equilibrium, temperature of neutron and heavy water will be same.

This common temperature is given as, T.

Also, we know that, kinetic energy of a particle

$$\text{KE} = \frac{p^2}{2m}$$

where, p = momentum of the particle

m = mass of the particle

Kinetic energy of the neutron is

$$\text{KE} = \frac{3}{2}kT$$

∴ de-Broglie wavelength of the neutron

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m(\text{KE})}}$$

$$= \frac{h}{\sqrt{2m \times \frac{3}{2}kT}} = \frac{h}{\sqrt{3mkT}}$$

62 An electron of mass m and a photon have same energy E. The ratio of de-Broglie wavelengths associated with them is **[NEET 2016]**

(a) $\left(\frac{E}{2m}\right)^{\frac{1}{2}}$ (b) $c(2mE)^{\frac{1}{2}}$

(c) $\frac{1}{c}\left(\frac{2m}{E}\right)^{\frac{1}{2}}$ (d) $\frac{1}{c}\left(\frac{E}{2m}\right)^{\frac{1}{2}}$

(c being velocity of light)

Ans. *(d)*

Since, it is given that electron has mass m. de-Broglie's wavelength for an electron will be given as

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$$\lambda_e = \frac{h}{P} \quad ...(i)$$

where, h = Planck's constant

P = Linear momentum of electron

As kinetic energy of electron

$$E = \frac{P^2}{2m} \Rightarrow P = \sqrt{2mE} \quad ...(ii)$$

From Eqs. (i) and (ii), we get

$$\lambda_e = \frac{h}{\sqrt{2mE}} \quad ...(iii)$$

Energy of a photon can be given as

$$E = h\nu$$

$$\Rightarrow \quad E = \frac{hc}{\lambda_p}$$

$$\Rightarrow \quad \lambda_p = \frac{hc}{E} \quad ...(iv)$$

Hence, λ_p = de-Broglie's wavelength of photon.

Now, divide Eq. (iii) by Eq. (iv), we get

$$\frac{\lambda_e}{\lambda_p} = \frac{h}{\sqrt{2mE}} \cdot \frac{E}{hc}$$

$$\Rightarrow \quad \frac{\lambda_c}{\lambda_p} = \frac{1}{c} \cdot \sqrt{\frac{E}{2m}}$$

63 Electrons of mass m with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength (λ_0) of the emitted X-ray is **[NEET 2016]**

(a) $\lambda_0 = \frac{2mc\lambda^2}{h}$

(b) $\lambda_0 = \frac{2h}{mc}$

(c) $\lambda_0 = \frac{2m^2c^2\lambda^3}{h^2}$

(d) $\lambda_0 = \lambda$

Ans. ***(a)***

Key Idea Cut-off wavelength occurs when incoming electron looses its complete energy in collision. This energy appears in the form of *X*-rays.

Given, mass of electrons = m

de-Broglie wavelength = λ

So, kinetic energy of electron = $\frac{p^2}{2m}$

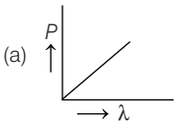
$$= \frac{\left(\frac{h}{\lambda}\right)^2}{2m} = \frac{h^2}{2m\lambda^2}$$

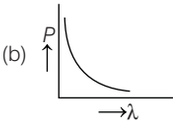
Now, maximum energy of photon can be given by

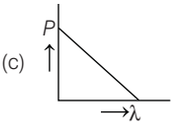
$$E = \frac{hc}{\lambda_0} = \frac{h^2}{2m\lambda^2}$$

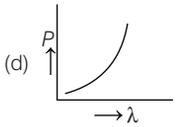
$$\Rightarrow \quad \lambda_0 = \frac{hc \times 2\lambda^2 \cdot m}{h^2} = \frac{2mc\lambda^2}{h}$$

64 Which of the following figures represent the variation of particle momentum and the associated de-Broglie wavelength? **[CBSE AIPMT 2015]**

(a) 

(b) 

(c) 

(d) 

Ans. ***(b)***

The de-Broglie wavelength is given by

$$\lambda = \frac{h}{P} \Rightarrow P\lambda = h$$

This equation is in the form of $yx = c$, which is the equation of a rectangular hyperbola. Hence, the graph given in option (b) is the correct one.

65 If the kinetic energy of the particle is increased to 16 times its previous value, the percentage change in the de-Broglie wavelength of the particle is **[CBSE AIPMT 2014]**

(a) 25 (b) 75

(c) 60 (d) 50

Ans. ***(b)***

For de-Broglie wavelength,

$$\lambda = \frac{h}{p}$$

For 1st case,

$$\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$$

For 2nd case,

$$\lambda_2 = \frac{h}{\sqrt{2m\,16K}}$$

$$= \frac{h}{4\sqrt{2mK}} = \frac{\lambda_1}{4}$$

$$\lambda_2 = 25\% \text{ of } \lambda_1$$

So, 75% change in the wavelength takes place.

66 The wavelength λ_e of an electron and λ_p of a photon of same energy E are related by **[NEET 2013]**

(a) $\lambda_p \propto \lambda_e^2$ (b) $\lambda_p \propto \lambda_e$

(c) $\lambda_p \propto \sqrt{\lambda_e}$ (d) $\lambda_p \propto \frac{1}{\sqrt{\lambda_e}}$

Ans. ***(a)***

Wavelength of electron is given by

$$\lambda_e = \frac{h}{p_e} = \frac{h}{\sqrt{2mE}} \quad [\because p_e = \sqrt{2mE}]$$

and for photon,

$$\lambda_p = \frac{hc}{E} \Rightarrow \lambda_e^2 = \frac{h^2}{2mE} \text{ or } E = \frac{hc}{\lambda_p}$$

$$\therefore \quad \lambda_e^2 = \frac{h^2}{2m \cdot \frac{hc}{\lambda_p}} \Rightarrow \lambda_e^2 = \frac{h^2}{2mhc}\lambda_p$$

$$\Rightarrow \lambda_e^2 \propto \lambda_p$$

67 A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of 3×10^6 ms^{-1}. The velocity of the particle is (mass of electron $= 9.1 \times 10^{-31}$ kg) **[CBSE AIPMT 2008]**

(a) 2.7×10^{-18} ms^{-1} (b) 9×10^{-2} ms^{-1}

(c) 3×10^{-31} ms^{-1} (d) 2.7×10^{-21} ms^{-1}

Ans. ***(a)***

According to de-Broglie relation, wavelength of a particle is given by

$$\lambda = \frac{h}{p}$$

where, h is Planck's constant and wavelength of an electron is given by

$$\lambda_e = \frac{h}{p_e}$$

but $\lambda = \lambda_e$, so $p = p_e$

or $m_e v_e = mv$ or $v = \frac{m_e v_e}{m}$

Here, $m_e = 9.1 \times 10^{-31}$ kg

$v_e = 3 \times 10^6$ ms^{-1}

and $m = 1$ mg

$= 1 \times 10^{-6}$ kg

$$\therefore \quad v = \frac{9.1 \times 10^{-31} \times 3 \times 10^6}{1 \times 10^{-6}}$$

$$= 2.7 \times 10^{-18} \text{ m/s}$$

68 The following particles are moving with the same velocity, then maximum de-Broglie wavelength will be for **[CBSE AIPMT 2002]**

(a) proton (b) α-particle

(c) neutron (d) β-particle

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Ans. *(d)*

de-Broglie wavelength is given by

$$\lambda = \frac{h}{mv}$$

For same velocity, $\lambda \propto \frac{1}{m}$

Out of the given particles, the mass of β-particle which is a fast moving electron, is minimum. Thus, de-Broglie wavelength is maximum for β-particle.

69 The energy of a photon of light is 3 eV. Then the wavelength of photon must be **[CBSE AIPMT 2000]**

(a) 4125 nm

(b) 412.5 nm

(c) 41250 nm

(d) 4 nm

Ans. *(b)*

If energy E is expressed in (eV) and wavelength λ (in Å), then energy of photon,

$$E = \frac{hc}{\lambda} = \frac{12375}{\lambda\,(\text{Å})}\,\text{eV}$$

$$\therefore\ \lambda = \frac{12375}{E\,(\text{eV})}\,\text{Å} \qquad [\because hc = 12375\,\text{eV-Å}]$$

$$= \frac{12375}{3\,(\text{eV})}\,\text{Å} = 4125\,\text{Å} = 412.5\,\text{nm}$$

Note

Energy of photon is $E = \frac{hc}{\lambda\,(\text{Å})} = \frac{12375}{\lambda\,(\text{Å})} eV$

Here, hc = 12375 eV-Å comes from the following procedure

hc = (Planck's constant) (velocity of light)

$$= \frac{(6.6 \times 10^{-34}\ J\text{-}s)\ (3 \times 10^{8}\ m/s)}{(1.6 \times 10^{-19}\ J/eV)}$$

$$= 12.375 \times 10^{-7}\ \text{eV-m}$$

$$= 12375\ \text{eV-Å}$$

70 The wavelength associated with an electron, accelerated through a potential difference of 100 V, is of the order of **[CBSE AIPMT 1996]**

(a) 1000 Å (b) 100 Å

(c) 10.5 Å (d) 1.2 Å

Ans. *(d)*

When electrons are accelerated through V volt, the gain in KE of the electron is given by

$$\frac{1}{2}mv^2 = \text{eV} \quad \text{or} \quad v^2 = \frac{2\text{eV}}{m}$$

Given, $V = 100$ V

So, $$v = \sqrt{\frac{2e(100)}{m}} \qquad ...(i)$$

According to de-Broglie theory, wavelength

$$\lambda = \frac{h}{mv}$$

$$\therefore\ \lambda = \frac{h}{m\sqrt{\frac{2e(100)}{m}}} = \frac{h}{\sqrt{2me(100)}}$$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 100}}$$

$$= 1.2 \times 10^{-10}$$

$$\Rightarrow \quad = 1.2\ \text{Å}$$

71 The de-Broglie wave corresponding to a particle of mass m and velocity v has a wavelength associated with it **[CBSE AIPMT 1989]**

(a) $\frac{h}{mv}$ (b) hmv

(c) $\frac{mh}{v}$ (d) $\frac{m}{hv}$

Ans. *(a)*

According to de-Broglie, a moving particle sometimes acts as a wave and sometimes as a particle. The wave associated with moving particle is called matter wave or de-Broglie wave whose wavelength is called de-Broglie wavelength and it is given by

$$\lambda = \frac{h}{mv}$$

where, m and v are the mass and velocity of the particle and h is Planck's constant.

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26
Atoms

TOPIC 1
Alpha-Particle Scattering and Rutherford Nuclear Model of Atom

01 When an α-particle of mass m moving with velocity v bombards on a heavy nucleus of charge Ze, its distance of closest approach from the nucleus depends on m as **[NEET 2016]**

(a) $\frac{1}{\sqrt{m}}$ (b) $\frac{1}{m^2}$

(c) m (d) $\frac{1}{m}$

Ans. *(d)*

When an α-particle of mass m moving with velocity v bombards on a heavy nucleus of charge Ze, then there will be no loss of energy as in this case, initial kinetic energy of α-particle = potential energy of α-particle at closest approach.

$$\Rightarrow \quad \frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\varepsilon_0 r_0}$$

$$\Rightarrow \quad r_0 \propto \frac{1}{m}$$

This is the required distance of closest approach to α-particle from the nucleus.

02 In a Rutherford scattering experiment when a projectile of charge Z_1 and mass M_1 approaches a target nucleus of charge Z_2 and mass M_2, the distance of closest approach is r_0. The energy of the projectile is **[CBSE AIPMT 2009]**

(a) directly proportional to $M_1 \times M_2$

(b) directly proportional to Z_1Z_2

(c) inversely proportional to Z_1

(d) directly proportional to mass M_1

Ans. *(b)*

A particle of mass M_1 and charge Z_1 possess initial velocity u, when it is at a large distance from the nucleus of an atom having atomic number Z_2. At the distance of closest approach, the kinetic energy of particle is completely converted to potential energy. Mathematically,

$$\frac{1}{2}M_1u^2 = \frac{1}{4\pi\varepsilon_0}\frac{Z_1Z_2}{r_0}$$

So, the energy of the particle is directly proportional to Z_1Z_2.

03 In Rutherford scattering experiment, what will be the correct angle for α-scattering for an impact parameter, $b = 0$? **[CBSE AIPMT 1994]**

(a) 90° (b) 270° (c) 0° (d) 180°

Ans. *(d)*

Impact parameter is perpendicular distance of the velocity vector of the alpha particle from the central line of the nucleus, when the particle is far away from the nucleus of the atom.

Rutherford calculated analytically, the relation between the impact parameter b and scattering angle θ, which is given by

$$b = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Ze^2\cot\frac{\theta}{2}}{E}$$

where, $E = \frac{1}{2}mv^2$ is kinetic energy of alpha particle, when it is far away from the atom.

According to problem,

$$b = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Ze^2\cot\frac{\theta}{2}}{E} = 0$$

As given that $b = 0$

so, $\cot\frac{\theta}{2} = 0 \Rightarrow \frac{\theta}{2} = 90° \text{ or } \theta = 180°$

TOPIC 2
Bohr Model and Hydrogen Spectra

04 The total energy of an electron in the nth stationary orbit of the hydrogen atom can be obtained by **[NEET (Oct.) 2020]**

(a) $E_n = \frac{13.6}{n^2}$ eV (b) $E_n = -\frac{13.6}{n^2}$ eV

(c) $E_n = -\frac{1.36}{n^2}$ eV (d) $E_n = -13.6 \times n^2$ eV

Ans. *(b)*

Total energy of an electron in the nth stationary orbit of hydrogen atom is given by

$$E_n = \frac{-Rhc}{n^2} = \frac{-13.6}{n^2}\text{ eV}$$

$[\because Rhc = 13.6\text{ eV}]$

05 For which one of the following, Bohr model is not valid? **[NEET (Sep.) 2020]**

(a) Singly ionised helium atom (He^+)

(b) Deuteron atom

(c) Singly ionised neon atom (Ne^+)

(d) Hydrogen atom

Ans. *(c)*

Since, Bohr's model is valid for hydrogen and hydrogen like atoms He^+, deuteron, etc. So, it is not valid for singly ionised neon atom (Ne^+).

Hence, correct option is (c).

06 The radius of the first permitted Bohr orbit for the electron, in a hydrogen atom equals 0.51 Å and its ground state energy equals −13.6 eV. If the electron in the hydrogen atom is replaced by

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muon (μ^{-1}) [Charge same as electron and mass 207 m_e], the first Bohr radius and ground state energy will be **[NEET (Odisha) 2019]**

(a) 0.53×10^{-13} m, – 3.6 eV
(b) 25.6×10^{-13} m, – 2.8 eV
(c) 2.56×10^{-13} m, – 2.8 keV
(d) 2.56×10^{-13} m, – 13.6 eV

Ans. *(c)*

Key Idea Hydrogen atom can be considered to be the system of two charges, positive charged nucleus and negative charged electron. A system of this kind is equivalent to a single particle of mass m' that revolves around the position of the heavier particle. Then, the reduced mass of electron is

$$m' = \frac{mM}{m+M}$$

where, m = mass of electron and
M = mass of nucleus
Its values is less than m.
Given, radius of first orbit for electron
$r_1 = 0.51$ Å,
ground state energy of electron,
$E_1 = -13.6$ eV,
mass of electron = m_e
mass of muon, $m_\mu = 207 m_e$ and
mass of nucleus, $M = 1836\, m_e$
When electron in hydrogen atom is replaced by muon, the reduced mass of muon is

$$m_\mu' = \frac{m_\mu M}{m_\mu + M} \quad ...(i)$$

Substituting the given values in Eq. (i), we get

$$m_\mu' = \frac{207 m_e \times 1836 m_e}{207 m_e + 1836 m_e}$$

$$\approx 186\, m_e \quad ...(ii)$$

The radius of first orbit in hydrogen atom for electron is given by,

$$r_1 = \frac{h^2 \varepsilon_0}{\pi m_e e^2} \quad ...(iii)$$

The radius of first orbit for muon is

$$r_1' = \frac{h^2 \varepsilon_0}{\pi m_\mu' e^2}$$

[$\because$ charge of μ = charge of e^-]

$$= \frac{h^2 \varepsilon_0}{\pi \times 186 m_e e^2} \quad [\text{from Eq. (ii)}]$$

$$= \left(\frac{h^2 \varepsilon_0}{\pi m_e e^2}\right)\frac{1}{186} = \frac{r_1}{186} \quad [\text{from Eq. (iii)}]$$

$$= \frac{0.51}{186}\text{Å} \quad [\because r_1 = 0.51\text{ Å}]$$

$$= 2.74\times10^{-13}\text{ m} \quad [\because 1\text{ Å} = 10^{-10}\text{ m}]$$

The total energy of electron is given by

$$E_n = \frac{-mZ^2e^4}{8\varepsilon_0^2 h^2}\left(\frac{1}{n^2}\right)$$

$$\Rightarrow \quad E_n \propto m$$

For electron in first orbit of hydrogen atom,

$$E_1 = km_e \quad ...(iv)$$

where, $k = \dfrac{e^4}{8\varepsilon_0^2 h^2}$ = constant.

For muon in first orbit

$$E_1' = km_\mu'$$
$$= k \times 186 m_e \quad [\text{from Eq. (i)}]$$
$$= 186 km_e$$
$$= 186 E_1 \quad [\text{from Eq. (iv)}]$$
$$= 186(-13.6)\text{ eV} \quad (\text{given})$$
$$= -2529.6\text{ eV}$$
$$= -2.5\text{ keV}$$

$\therefore$ The values are closest to that of options (c).

07 The total energy of an electron in an atom in an orbit is –3.4 eV. Its kinetic and potential energies are, respectively:
[NEET (National) 2019]

(a) –3.4 eV, –6.8 eV (b) 3.4 eV, –6.8 eV
(c) 3.4 eV, 3.4 eV (d) –3.4 eV, –3.4 eV

Ans. *(b)*

According to Bohr's model, the kinetic energy of electron in term of Rydberg constant R is given by

$$\text{KE} = \frac{Rhc}{n^2} \quad ...(i)$$

where, h = Planck's constant,
c = speed of light
and n = principal quantum number.
Similarly, potential energy is given by,

$$\text{PE} = -\frac{2Rhc}{n^2} \quad ...(ii)$$

$\therefore$ Total energy, E = PE + KE

$$= -\frac{Rhc}{n^2} \quad [\text{from Eqs. (i) and (ii)}]$$

$\Rightarrow$ KE = – E and PE = 2E
Given, $E = -3.4$ eV
$\therefore$ KE = – (–3.4) = 3.4 eV
and PE = 2 (– 3.4) = – 6.8 eV

08 The ratio of kinetic energy to the total energy of an electron in a Bohr orbit of the hydrogen atom, is
[NEET 2018]

(a) 2 : –1 (b) 1 : –1 (c) 1 : 1 (d) 1 : –2

Ans. *(b)*

Kinetic energy of an electron in a Bohr orbit of a hydrogen atom is given as

$$\text{KE}_n = \frac{Rhc}{n^2} \quad ...(i)$$

Total energy of an electron in a Bohr orbit of a hydrogen atom is given as

$$\text{TE}_n = \frac{-Rhc}{n^2} \quad ...(ii)$$

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{\text{KE}_n}{\text{TE}_n} = \frac{\left(\frac{Rhc}{n^2}\right)}{-\left(\frac{Rhc}{n^2}\right)}$$

$\Rightarrow$ $\text{KE}_n : \text{TE}_n = 1 : -1$

09 The ratio of wavelengths of the last line of Balmer series and the last line of Lyman series is **[NEET 2017]**

(a) 2 (b) 1
(c) 4 (d) 0.5

Ans. *(c)*

Wavelength of spectral lines are given by

$$\frac{1}{\lambda} = z^2 R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

For last line of Balmer series,

$$n_1 = 2 \text{ and } n_2 = \infty$$

$$\Rightarrow \quad \frac{1}{\lambda_B} = z^2 R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4} \qquad [\because z = 1]$$

Similarly, for last line of Lyman series,

$$n_1 = 1 \text{ and } n_2 = \infty$$

$$\Rightarrow \quad \frac{1}{\lambda_2} = z^2 R\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = R$$

$$\therefore \quad \frac{\frac{1}{\lambda_B}}{\frac{1}{\lambda_L}} = \frac{\frac{R}{4}}{R} = \frac{1}{4}$$

$$\Rightarrow \quad \frac{\lambda_L}{\lambda_B} = \frac{1}{4} \Rightarrow \frac{\lambda_B}{\lambda_L} = 4$$

10 If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength λ. When it jumps from the 4th orbit to the 3rd orbit, the corresponding wavelength of the photon will be **[NEET 2016]**

(a) $\frac{16}{25}\lambda$ (b) $\frac{9}{16}\lambda$
(c) $\frac{20}{7}\lambda$ (d) $\frac{20}{13}\lambda$

Ans. *(c)*

Key Idea Excess energy of e^- appears as photon.

From Rydberg's formula,

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5R}{36}$$

$$\frac{1}{\lambda'} = R\left(\frac{1}{3^2} - \frac{1}{4^2}\right) = \frac{7R}{144}$$

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$$\frac{1}{\lambda}/\frac{1}{\lambda'}=\frac{5R}{36}\div\frac{7R}{144}$$

$$\Rightarrow \quad \frac{\lambda'}{\lambda}=\frac{5R}{36}\times\frac{144}{7R}=\frac{20}{7}$$

$$\Rightarrow \quad \lambda'=\frac{20}{7}\lambda$$

11 A proton and an alpha particle both enter a region of uniform magnetic field B, moving at right angles to the field B. If the radius of circular orbits for both the particles is equal and the kinetic energy acquired by proton is 1 MeV, the energy acquired by the alpha particle will be **[CBSE AIPMT 2015]**

(a) 4 MeV (b) 0.5 MeV
(c) 1.5 MeV (d) 1 MeV

Ans. *(d)*

Radius in magnetic fields of circular orbit,

$$R=\frac{mV}{qB}=\frac{\sqrt{2mE}}{qB}$$

and total energy of a moving particle in a circular orbit, $E=\frac{q^2B^2R^2}{2m}$

For a proton enter in a region of magnetic field,

$$E_1=\frac{e^2\times B^2\times R^2}{2\times m_P} \qquad ...(i)$$

where m_P is the mass of proton.

Similarly, for a α-particle moves in a uniform magnetic field

$$E_2=\frac{(2e)^2\times B^2\times R^2}{2\times(4m_P)}$$

$[\because m_\alpha=4m_P]$ ...(ii)

Dividing Eq. (ii) by Eq. (i), we get

$$\frac{E_2}{E_1}=\frac{(2e)^2\times B^2\times R^2}{2\times(4m_P)}\times\frac{2\times m_P}{e^2\times B^2\times R^2}$$

$$\frac{E_2}{E_1}=1 \Rightarrow E_2=E_1=1\,\text{MeV}$$

12 In the spectrum of hydrogen, the ratio of the longest wavelength in the Lyman series to the longest wavelength in the Balmer series is **[CBSE AIPMT 2015]**

(a) $\frac{4}{9}$ (b) $\frac{9}{4}$ (c) $\frac{27}{5}$ (d) $\frac{5}{27}$

Ans. *(d)*

In hydrogen atom, wavelength of characteristic spectrum

$$\frac{1}{\lambda}=Rz^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$$

For Lyman series $n_1=1, n_2=2$

$$\frac{1}{\lambda_1}=Rz^2\left[\frac{1}{(1)^2}-\frac{1}{(2)^2}\right] \qquad ...(i)$$

For Balmer series $n_1=2, n_2=3$

$$\frac{1}{\lambda_2}=Rz^2\left[\frac{1}{(2)^2}-\frac{1}{(3)^2}\right] \qquad ...(ii)$$

Dividing Eq. (ii) by Eq. (i) we get

$$\frac{\lambda_1}{\lambda_2}=\frac{Rz^2\left[\frac{1}{4}-\frac{1}{9}\right]}{Rz^2\left[1-\frac{1}{4}\right]}=\frac{\frac{5}{36}}{\frac{3}{4}}$$

$$\frac{\lambda_1}{\lambda_2}=\frac{5}{36}\times\frac{4}{3}=\frac{5}{27}$$

13 Consider 3rd orbit of He^+ (Helium), using non-relativistic approach, the speed of electron in this orbit will be (given $K=9\times10^9$ constant, $Z=2$ and h (Planck's constant) $=6.6\times10^{-34}$ J-s) **[CBSE AIPMT 2015]**

(a) 2.92×10^6 m/s (b) 1.46×10^6 m/s
(c) 0.73×10^6 m/s (d) 3.0×10^8 m/s

Ans. *(b)*

Energy of electron in the 3rd orbit of He^+ is

$$E_3=-13.6\times\frac{Z^2}{n^2}\,\text{eV}=-13.6\times\frac{4}{3^2}\,\text{eV}$$

$$=-13.6\times\frac{4}{9}\times1.6\times10^{-19}\,\text{J}$$

From Bohr's model,

$$E_3=-KE_3=-\frac{1}{2}m_ev^2$$

$$\Rightarrow \frac{1}{2}\times9.1\times10^{-31}\times v^2$$

$$=-13.6\times\frac{4}{9}\times1.6\times10^{-19}$$

$$\Rightarrow \quad v^2=\frac{136\times16\times4\times2\times10^{-11}}{9\times91}$$

or, $v=1.46\times10^6$ m/s

14 Hydrogen atom in ground state is excited by a monochromatic radiation of $\lambda=975$ Å. Number of spectral lines in the resulting spectrum emitted will be **[CBSE AIPMT 2014]**

(a) 3 (b) 2 (c) 6 (d) 10

Ans. *(c)*

Energy provided to the ground state electron

$$=\frac{hc}{\lambda}=\frac{6.6\times10^{-34}\times3\times10^8}{975\times10^{-10}}$$

$$=\frac{6.6\times3}{975}\times10^{-16}$$

$$=0.020\times10^{-16}=2\times10^{-18}\,\text{J}$$

$$=\frac{20\times10^{-19}}{1.6\times10^{-19}}\text{eV}=\frac{20}{1.6}\text{eV}=12.75\,\text{eV}$$

It means the electron jumps to $n=4$ from $n=1$.

When electron will fall back, number of spectral lines emitted

$$=\frac{n(n-1)}{2}=\frac{4(4-1)}{2}=6$$

15 Ratio of longest wavelengths corresponding to Lyman and Balmer series in hydrogen spectrum is **[NEET 2013]**

(a) $\frac{5}{27}$ (b) $\frac{3}{23}$ (c) $\frac{7}{29}$ (d) $\frac{9}{31}$

Ans. *(a)*

Wavelength for Lyman series

$$\lambda_L=\frac{1}{R\left(1-\frac{1}{4}\right)}=\frac{4}{3R}$$

and wavelength for Balmer series

$$\lambda_B=\frac{1}{R\left(\frac{1}{4}-\frac{1}{9}\right)}=\frac{1}{R\left(\frac{5}{36}\right)}=\frac{36}{5R}$$

$$\therefore \frac{\lambda_L}{\lambda_B}=\frac{4}{3R}\times\frac{5R}{36}=\frac{5}{27}\Rightarrow\lambda_L:\lambda_B=5:27$$

16 Monochromatic radiation emitted when electron state on hydrogen atom jumps from first excited state to the ground state irradiates a photosensitive material. The stopping potential is measured to be 3.57 V. The threshold frequency of the material is **[CBSE AIPMT 2012]**

(a) 4×10^{15} Hz (b) 5×10^{15} Hz
(c) 1.6×10^{15} Hz (d) 2.5×10^{15} Hz

Ans. *(c)*

Concept When an electron in hydrogen atom jumps from first excited state ($n=2$) to ground state ($n=1$) energy is released and is given by

$$E=E_{(n=2)}-E_{(n=1)}$$

where, $E_n=-\frac{13.6}{n^2}\text{eV}$

Energy released from emission of electron is given by

$$E=-3.4-(-13.6)$$

$$=10.2\,\text{eV}$$

Now, from photoelectric equation, work function,

$$\phi=E-eV=h\nu$$

$$\nu=\frac{E-eV}{h}=\frac{(10.2-3.57)e}{6.67\times10^{-34}}$$

$$\nu=\frac{6.63\times1.6\times10^{-19}}{6.67\times10^{-34}}=1.6\times10^{15}\,\text{Hz}$$

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17 Electron in hydrogen atom first jumps from third excited state to second excited state and then from second excited to the first excited state. The ratio of the wavelengths $\lambda_1 : \lambda_2$ emitted in the two cases is **[CBSE AIPMT 2012]**

(a) 7/5 (b) 27/20
(c) 27/5 (d) 20/7

Ans. *(d)*

According to question,
for wavelength λ_1, $n_1 = 4$ and $n_2 = 3$
and for λ_2, $n_1 = 3$ and $n_2 = 2$

and we know that, $\frac{hc}{\lambda} = -13.6\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

So, for λ_1

$$\Rightarrow \quad \frac{hc}{\lambda_1} = -13.6\left[\frac{1}{(4)^2} - \frac{1}{(3)^2}\right]$$

$$\frac{hc}{\lambda_1} = 13.6\left[\frac{7}{144}\right] \qquad ...(i)$$

Similarly, for λ_2

$$\Rightarrow \quad \frac{hc}{\lambda_2} = -13.6\left[\frac{1}{(3)^2} - \frac{1}{(2)^2}\right]$$

$$\frac{hc}{\lambda_2} = 13.6\left[\frac{5}{36}\right] \qquad ...(ii)$$

Hence, from Eqs. (i) and (ii), we get

$$\frac{\lambda_1}{\lambda_2} = \frac{20}{7}$$

18 An electron of a stationary hydrogen atom passes from the fifth energy level to the ground level. The velocity 3that the atom acquired as a result of photon emission will be **[CBSE AIPMT 2012]**

(a) $\frac{24hR}{25m}$ (b) $\frac{25hR}{24m}$ (c) $\frac{25m}{24hR}$ (d) $\frac{24m}{25hR}$

(m is the mass of electron, R is Rydberg constant and h is Planck's constant.)

Ans. *(a)*

Concept According to third postulate of Bohr's model, when an atom makes a transition from higher energy state to lower energy state, the difference of energy is carried away by a photon such that $h\nu = E_{n_i} - E_{n_f}$ or $\frac{hc}{\lambda} = Rhc\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$

[where, n_i = quantum number of higher energy state and n_f = quantum number of lower energy state.]

Energy difference between fifth and first orbit is $E_5 - E_1 = \frac{hc}{\lambda}$ and

$$Rhc - \frac{Rhc}{25} = \frac{hc}{\lambda}$$

$$\frac{24}{25}R = \frac{1}{\lambda}$$

As, $p = \frac{h}{\lambda}$ and $v = \frac{h}{m\lambda} = \frac{24}{25}\frac{Rh}{m}$

19 The wavelength of the first line of Lyman series for hydrogen atom is equal to that of the second line of Balmer series for a hydrogen like ion. The atomic number Z of hydrogen like ion is **[CBSE AIPMT 2011]**

(a) 4 (b) 1 (c) 2 (d) 3

Ans. *(c)*

For Lyman series for H-atom

$$\frac{hc}{\lambda} = Rhc\left(\frac{1}{1^2} - \frac{1}{2^2}\right)$$

and for H-like ion,

$$\frac{hc}{\lambda} = Z^2 Rhc\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\therefore \left(\frac{1}{1^2} - \frac{1}{2^2}\right) = Z^2\left(\frac{1}{4} - \frac{1}{16}\right)$$

$$\left(1 - \frac{1}{4}\right) = Z^2\left(\frac{1}{4} - \frac{1}{16}\right) \Rightarrow Z = 2$$

20 The energy of a hydrogen atom in the ground state is – 13.6 eV. The energy of a He^+ ion in the first excited state will be **[CBSE AIPMT 2010]**

(a) –13.6 eV (b) –27.2 eV
(c) – 54.4 eV (d) – 6.8 eV

Ans. *(a)*

Energy E of an atom with principal quantum number n is given by

$E = \frac{-13.6}{n^2} Z^2$ for first excited state $n = 2$

and for He^+, $Z = 2$

So, $E = \frac{-13.6 \times (2)^2}{(2)^2} = -13.6\,\text{eV}$

21 The ionisation energy of the electron in the hydrogen atom in its ground state is 13.6 eV. The atoms are excited to higher energy levels to emit radiations of 6 wavelengths. Maximum wavelength of emitted radiation corresponds to the transition between **[CBSE AIPMT 2009]**

(a) $n = 3$ to $n = 2$ states
(b) $n = 3$ to $n = 1$ states
(c) $n = 2$ to $n = 1$ states
(d) $n = 4$ to $n = 3$ states

Ans. *(d)*

Number of spectral lines

$$N = \frac{n(n-1)}{2} \Rightarrow \frac{n(n-1)}{2} = 6$$

or $n^2 - n - 12 = 0$
or $(n-4)(n+3) = 0$ or $n = 4$

Now as the first line of the series has the maximum wavelength, therefore electron jumps from the fourth orbit to the third orbit.

22 The ground state energy of hydrogen atom is –13.6 eV. When its electron is in the first excited state, its excitation energy is **[CBSE AIPMT 2008]**

(a) 3.4 eV (b) 6.8 eV
(c) 10.2 eV (d) zero

Ans. *(c)*

In the ground state, $n = 1$

$$E_1 = -\frac{13.6}{1^2} = -13.6\,\text{eV}$$

For the first excited state (i.e. for $n = 2$)

$$E_2 = \frac{-13.6}{2^2} = -3.4\,\text{eV}$$

$$\Delta E = E_2 - E_1$$
$$= -3.4 + 13.6 = 10.2\,\text{eV}$$

23 The total energy of electron in the ground state of hydrogen atom is –13.6 eV. The kinetic energy of an electron in the first excited state is **[CBSE AIPMT 2007]**

(a) 3.4 eV (b) 6.8 eV
(c) 13.6 eV (d) 1.7 eV

Ans. *(a)*

The energy of hydrogen atom when the electron revolves in nth orbit is given by

$$E = \frac{-13.6Z^2}{n^2}\,\text{eV} \qquad [Z = 1]$$

In the ground state; $n = 1$

$$E = \frac{-13.6}{1^2} = -13.6\,\text{eV}$$

For $n = 2$,

$$E = \frac{-13.6}{2^2} = -3.4\,\text{eV}$$

So, kinetic energy of electron in the first excited state (i.e. for $n = 2$) is

$$KE = -E = -(-3.4) = 3.4\,\text{eV}$$

24 In a discharge tube ionisation of enclosed gas is produced due to collisions between **[CBSE AIPMT 2006]**

(a) positive ions and neutral atoms/molecules
(b) negative electrons and neutral atoms/molecules
(c) photons and neutral atoms/molecules
(d) neutral gas atoms/molecules

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Ans. *(b)*

In a discharge tube, after being accelerated though a high potential difference the ions in the gas strike the cathode with huge kinetic energy. This collision liberates electrons from the cathode. These free electrons can further liberate ions from gas molecules through collisions. The positive ions are attracted towards the cathode and negatively charged electrons move towards anode. Thus, ionisation of gas results.

25 Ionisation potential of hydrogen atom is 13.6 eV. Hydrogen atoms in the ground state are excited by monochromatic radiation of photon energy 12.1 eV. According to Bohr's theory, the spectral lines emitted by hydrogen will be **[CBSE AIPMT 2006]**

(a) two (b) three
(c) four (d) one

Ans. *(b)*

Ionisation energy corresponding to ionisation potential ($E_1 = -13.6$ eV)

Photon energy incident (ΔE) = 12.1 eV

So, the energy of electron in excited state (E_2) is given by

$$E_2 - E_1 = \Delta E \Rightarrow E_2 = \Delta E + E_1$$

$$\Rightarrow \quad E_2 = -13.6 + 12.1$$

$$\Rightarrow \quad E_2 = -1.5 \text{ eV}$$

i.e. $$E_2 = -\frac{13.6}{n^2} \text{ eV}$$

$$-1.5 = \frac{-13.6}{n^2}$$

$$\Rightarrow \quad n^2 = \frac{-13.6}{-1.5} \approx 9$$

$$\therefore \quad n = 3$$

i.e. energy of electron in excited state corresponds to third orbit.

The possible spectral lines is given by

$$\frac{n(n-1)}{2} \Rightarrow \frac{3(3-1)}{2} \Rightarrow 3$$

26 The total energy of an electron in the first excited state of hydrogen is about – 3.4 eV. Its kinetic energy in this state is **[CBSE AIPMT 2005]**

(a) – 3.4 eV (b) – 6.8 eV
(c) 6.8 eV (d) 3.4 eV

Ans. *(d)*

Kinetic energy of electron

$$\text{KE} = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

Potential energy of electron

$$U = -\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

$\therefore$ Total energy $E = \text{KE} + U$

$$= \frac{Ze^2}{8\pi\varepsilon_0 r} - \frac{Ze^2}{4\pi\varepsilon_0 r}$$

or $$E = -\frac{Ze^2}{8\pi\varepsilon_0 r} \quad \text{or} \quad E = -\text{KE}$$

or $$\text{KE} = -E = -(-3.4) = 3.4 \text{ eV}$$

NOTE

Total kinetic energy of a revolving electron in any given orbit is equal to the negative of total energy of electrons in that orbit i.e. $KE = -E$

27 Energy E of a hydrogen atom with principal quantum number n is given by $E = \frac{-13.6}{n^2}$ eV. The energy of a photon ejected when the electron jumps from $n = 3$ state to $n = 2$ state of hydrogen, is approximately **[CBSE AIPMT 2004]**

(a) 1.5 eV (b) 0.85 eV
(c) 3.4 eV (d) 1.9 eV

Ans. *(d)*

Given, $E_n = -\frac{13.6}{n^2}$ eV

Energy of photon ejected when electron jumps from $n = 3$ to $n = 2$ state is given by

$$\Delta E = E_3 - E_2$$

Energy of third orbit

$$E_3 = -\frac{13.6}{(3)^2} \text{eV} = -\frac{13.6}{9} \text{eV}$$

Energy of second orbit

$$E_2 = -\frac{13.6}{(2)^2} \text{eV} = -\frac{13.6}{4} \text{eV}$$

So, $$\Delta E = E_3 - E_2 = -\frac{13.6}{9} - \left(-\frac{13.6}{4}\right)$$

$$= 1.9 \text{ eV} \quad \text{(approximately)}$$

28 The Bohr model of atoms **[CBSE AIPMT 2004]**

(a) assumes that the angular momentum of electrons is quantised
(b) uses Einstein's photoelectric equation
(c) predicts continuous emission spectra for atoms
(d) predicts the same emission spectra for all types of atoms

Ans. *(a)*

According to Bohr's hypothesis, electron can revolve only in those orbits in which its angular momentum is an integral multiple of $\frac{h}{2\pi}$, where h is Planck's constant. In these orbits, angular momentum of electron can have magnitude as $\frac{h}{2\pi}, \frac{2h}{2\pi}, \frac{3h}{2\pi}$ ..... etc., but never as $\frac{1.5h}{2\pi}, \frac{2.5h}{2\pi}, \frac{3.5h}{2\pi}$ ..... etc. This is called the quantisation of angular momentum.

29 Which of the following transitions gives photon of maximum energy? **[CBSE AIPMT 2000]**

(a) $n = 1$ to $n = 2$ (b) $n = 2$ to $n = 1$
(c) $n = 2$ to $n = 6$ (d) $n = 6$ to $n = 2$

Ans. *(b)*

Energy levels of H-atom are given by

$$E_n = -\frac{13.6Z^2}{n^2} \text{eV} \qquad (Z = 1)$$

$$\Rightarrow \quad E_n = -13.6/n^2 \text{ eV}$$

Photons are emitted only when electron jumps from higher energy level (higher n-value) to lower energy level (lower n-value). So, alternative (a) and (c) are wrong.

Energy difference from $n = 2$ to $n = 1$ level is

$$\Delta E_{2\to 1} = 13.6\left(\frac{1}{1^2} - \frac{1}{2^2}\right)\text{eV}$$

$$= 13.6 \times \frac{3}{4} = 10.2 \text{ eV}$$

Energy difference from $n = 6$ to $n = 2$ level is

$$\Delta E_{6\to 2} = 13.6\left(\frac{1}{2^2} - \frac{1}{6^2}\right)$$

$$= 13.6 \times \left(\frac{1}{4} - \frac{1}{36}\right) = 13.6 \times \frac{2}{9}$$

$$= 3.02 \text{ eV}$$

Thus, it is evident that difference is larger for $n = 2$ to $n = 1$ transition. Hence, maximum energy photon or shortest wavelength will be emitted during transition from $n = 2$ to $n = 1$

30 When electron jumps from $n = 4$ to $n = 2$ orbit, we get **[CBSE AIPMT 2000]**

(a) second line of Lyman series
(b) second line of Balmer series
(c) second line of Paschen series
(d) an absorption line of Balmer series

Ans. *(b)*

(a) Second line of Lyman series corresponds to the transition $n = 3 \to n = 1$
(b) Second line of Balmer series corresponds to the transition $n = 4 \to n = 2$
(c) Second line of Paschen series corresponds to the transition $n = 5 \to n = 3$

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(d) An absorption line of Balmer series arises when electron jumps from $n=2$ to any other higher state.

Thus, choice (b) is correct.

NOTE

For Lyman series

$$n_2 = 2, 3, 4 \ldots\ldots \rightarrow n_1 = 1$$

For Balmer series

$$n_2 = 3, 4, 5, \ldots\ldots \rightarrow n_1 = 2$$

For Paschen Series

$$n_2 = 4, 5, 6 \ldots \rightarrow n_1 = 3$$

For Brackett series

$$n_2 = 5, 6, 7 \ldots\ldots \rightarrow n_1 = 4$$

For Pfund series

$$n_2 = 6, 7, 8 \ldots\ldots \rightarrow n_1 = 5$$

31 In the Bohr's model of a hydrogen atom, the centripetal force is furnished by the Coulomb attraction between the proton and the electron. If a_0 is the radius of the ground state orbit, m is the mass and e is the charge on the electron, ε_0 is the vacuum permittivity, the speed of the electron is **[CBSE AIPMT 1998]**

(a) zero (b) $\frac{e}{\sqrt{\varepsilon_0 a_0 m}}$

(c) $\frac{e}{\sqrt{4\pi\varepsilon_0 a_0 m}}$ (d) $\frac{\sqrt{4\pi\varepsilon_0 a_0 m}}{e}$

Ans. *(c)*

From Coulomb's attraction between the positive proton and negative electron

$$= \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

[For neutral atom]

Centripetal force has magnitude

$$F = \frac{mv^2}{r}$$

So for the revolving electrons

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$\Rightarrow \quad v^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{mr}$$

or $$v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$$

For ground state of H-atom, $r = a_0$

$$\therefore \quad v = \frac{e}{\sqrt{4\pi\varepsilon_0 m a_0}}$$

32 The energy of ground electronic state of hydrogen atom is –13.6 eV. The energy of the first excited state will be **[CBSE AIPMT 1997]**

(a) –54.4 eV
(b) –27.2 eV
(c) – 6.8 eV
(d) – 3.4 eV

Ans. *(d)*

The energy of hydrogen like atom in its nth excited state is given by

$$E_n = -13.6\frac{Z^2}{n^2}.$$

For ground state (n=1),

and atomic number (Z) = 1

$$E_1 = -\frac{13.6}{(1)^2} = -13.6\,\text{eV}$$

For first excited state (n=2),

$$E_2 = -\frac{13.6}{(2)^2} = -\frac{13.6}{4}$$

$$= -3.4\,\text{eV}$$

Note

In ground state ($n = 1$) energy of atom is –13.6 eV and energy corresponding to $n = \infty$ is zero. Therefore, energy required to remove the electron from ground state is 13.6 eV.

33 When hydrogen atom is in its first excited level, its radius is **[CBSE AIPMT 1997]**

(a) four times, its ground state radius
(b) twice, its ground state radius
(c) same as its ground sate radius
(d) half of its ground state radius

Ans. *(a)*

The radius of nth Bohr's orbit of hydrogen and hydrogen like atom

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2 Z} \quad .$$

$$\therefore \quad r_n = \frac{n^2 a_0}{Z} \quad \text{or} \quad r_n \propto \frac{n^2}{Z}$$

For ground state, $n = 1$

Atomic number, $Z = 1$

For first excited state, $n = 2$

$$\therefore \quad \frac{r_2}{r_1} = \left(\frac{2}{1}\right)^2 = 4$$

or $$r_2 = 4r_1$$

Therefore, radius of first excited state is 4 times than that of ground state radius in H-atom.

34 When a hydrogen atom is raised from the ground state to an excited state **[CBSE AIPMT 1995]**

(a) PE decreases and KE increases
(b) PE increases and KE decreases
(c) both KE and PE decrease
(d) absorption spectrum

Ans. *(c)*

Kinetic energy of electron is given by

$$\text{KE} = \frac{kZe^2}{2r}$$

Potential energy of electron is

$$U = -\frac{kZe^2}{r}$$

When a hydrogen atom is raised from the ground, to an excited state both potential energy and kinetic energy decreases.

35 The spectrum obtained from a sodium vapour lamp is an example of **[CBSE AIPMT 1995]**

(a) band spectrum (b) continuous spectrum
(c) emission spectrum
(d) absorption spectrum

Ans. *(c)*

When continuous light from a source is examined directly in a spectroscope, we observe the emission spectrum of the source. The sodium vapour spectrum, consists of a few isolated bright lines. Each bright line corresponds to a particular wavelength. It is emitted by the atoms in the gaseous state.

When continuous light from a source is made to pass through an absorbing substance and then examined in a spectroscope, we observe absorption spectrum of the substance.

A band spectrum is emitted by chemical compounds in the vapour state. It is therefore a molecule spectrum.

A continuous emission spectrum consists of a wide range of unseparated wavelengths.

36 Doubly ionised helium atoms and hydrogen ions are accelerated from rest through the same potential drop. The ratio of the final velocities of the helium and the hydrogen ion is **[CBSE AIPMT 1994]**

(a) $\frac{1}{2}$ (b) 2

(c) $\frac{1}{\sqrt{2}}$ (d) $\sqrt{2}$

Ans. *(c)*

If v is the speed acquired by particle when accelerated under a potential difference V, then

KE gained by particle $= \frac{1}{2}mv^2 = eV$

or $$v = \sqrt{\frac{2eV}{m}}$$

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So, for two different cases of the He-atom and H-atom,

$$\frac{v_{He}}{v_H} = \frac{\sqrt{\frac{2(e)_{He}V}{m_{He}}}}{\sqrt{\frac{2(e)_H V}{m_H}}}$$

As $m_{He} = 4m_H$ and $(e)_{He} = 2(e)_H$

$\therefore \quad \frac{v_{He}}{v_H} = \frac{1}{\sqrt{2}}$

37 The radius of hydrogen atom in its ground state is 5.3×10^{-11} m. After collision with an electron it is found to have a radius of 21.2×10^{-11} m. What is the principal quantum number n of the final state of the atom ? **[CBSE AIPMT 1994]**

(a) $n=4$ (b) $n=2$
(c) $n=16$ (d) $n=3$

Ans. *(b)*

Radii of Bohr's stationary orbit is given by

$$r = \frac{n^2h^2}{4\pi^2 mke^2 Z} \Rightarrow r \propto \frac{n^2}{Z}$$

Considering two situations of electrons,

$$\Rightarrow \quad \frac{(r_f)}{(r_i)} = \frac{n_f^2}{n_i^2}$$

For ground state $n_i = 1$

$$\therefore \quad \frac{21.2\times10^{-11}}{5.3\times10^{-11}} = n_f^2$$

or $n_f^2 = 4$

$\therefore \quad n_f = 2$

38 Hydrogen atoms are excited from ground state of the principal quantum number 4. Then, the number of spectral lines observed will be **[CBSE AIPMT 1993]**

(a) 3 (b) 6
(c) 5 (d) 2

Ans. *(b)*

Number of spectral lines observed in hydrogen spectrum is given by

$$= \frac{n(n-1)}{2} = \frac{4(4-1)}{2} = 6$$

Where, n = principal quantum number = number of orbits.

39 Which source is associated with a line emission spectrum? **[CBSE AIPMT 1993]**

(a) Electric fire
(b) Neon street sign
(c) Red traffic light
(d) Sun

Ans. *(b)*

In line emission spectrum, every line spectrum consists of a few isolated bright lines, each bright line corresponds to a particular wavelength. It is emitted by atoms in the gaseous state.

e.g. a sodium discharge lamp, a mercury vapour lamp, a neon discharge tube and a helium discharge tube all emit sharp lines of definite wavelengths.

40 The ionisation energy of hydrogen atom is 13.6 eV. Following Bohr's theory, the energy corresponding to a transition between 3rd and 4th orbit is **[CBSE AIPMT 1992]**

(a) 3.40 eV (b) 1.51 eV
(c) 0.85 eV (d) 0.66 eV

Ans. *(d)*

Total energy of electron for hydrogen like atom is given by

$$E_n = -\frac{13.6Z^2}{n^2}$$

$$\therefore \quad E_3 = -\frac{13.6}{3^2}\text{ eV} \qquad [Z=1, n=3]$$

$$= -1.51\text{ eV}$$

$$E_4 = -\frac{13.6}{4^2} = -0.85\text{ eV}$$

$\therefore \quad E_4 - E_3 = 1.51 - 0.85 = 0.66$ eV

41 In terms of Bohr radius a_0, the radius of the second Bohr orbit of a hydrogen atom is given by **[CBSE AIPMT 1992]**

(a) $4a_0$ (b) $8a_0$
(c) $\sqrt{2}a_0$ (d) $2a_0$

Ans. *(a)*

From Bohr's postulate, for any permitted (stationary orbit).

Angular momentum of electron revolving in an orbit is constant

i.e. $mvr = \frac{nh}{2\pi}$ or $v = \frac{nh}{2\pi mr}$ ...(i)

Also, $\frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2} = \frac{kZe^2}{r^2}$ ...(ii)

(where, $k = \frac{1}{4\pi\varepsilon_0}$)

Symbols have their usual meaning.

From Eqs. (i) and (ii),

$$r = \frac{n^2h^2}{4\pi^2 mkZe^2}$$

For hydrogen atom,

$$Z = 1$$

$$\therefore \quad r = \frac{n^2h^2}{4\pi^2 mke^2}$$

$$\Rightarrow \quad r_n \propto n^2$$

$$\therefore \quad a_2 = 4a_0$$

Note

For solving the problem, dependence of radius of nth orbit of hydrogen like atom must be kept in mind i.e. $r_n \propto \frac{n^2}{Z}$

[where, n = nth orbit and Z = atomic number]

42 The ground state energy of H-atom is 13.6 eV. The energy needed to ionise H-atom from its second excited state **[CBSE AIPMT 1991]**

(a) 1.51 eV (b) 3.4 eV
(c) 13.6 eV (d) 12.1 eV

Ans. *(a)*

For second excited state, $n=3$

$\therefore$ Energy needed to ionise H-atom from its second excited state

$$E = \frac{2\pi^2 mke^4}{h^2}\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$$

or we can say that

$$E \propto \frac{Z^2}{n^2}$$

(Z = atomic number, n = nth orbit)

So, $E = \frac{13.6}{3^2}\text{ eV} = 1.51\text{eV}$

43 Consider an electron in the nth orbit of a hydrogen atom in the Bohr model. The circumference of the orbit can be expressed in terms of de-Broglie wavelength λ of that electron as **[CBSE AIPMT 1990]**

(a) $(0.529)n\lambda$ (b) $\sqrt{n\lambda}$
(c) $(13.6)\lambda$ (d) $n\lambda$

Ans. *(d)*

The circumference of an orbit in an atom in terms of wavelength of wave associated with electron is given by

$$2\pi r_n = n\lambda$$

[r_n = radius of any n orbit]

44 The valence electron in alkali metal is a **[CBSE AIPMT 1990]**

(a) f-electron (b) p-electron
(c) s-electron (d) d-electron

Ans. *(c)*

The outermost electrons in an atom are called valence electrons. In alkali metals (IA group) outermost electron is present in s-orbital. Alkali metals have one valence electron. e.g. Li, Na, K.

45 Energy levels A, B, C of a certain atom correspond to increasing values of energy i.e. $E_A < E_B < E_C$. If $\lambda_1, \lambda_2, \lambda_3$ are the wavelengths of radiation corresponding to the

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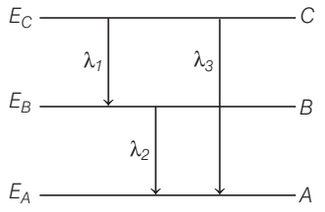
transitions C to B, B to A and C to A respectively, which of the following relation is correct ?

[CBSE AIPMT 1990]

(a) $\lambda_3 = \lambda_1 + \lambda_2$ (b) $\lambda_3 = \dfrac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$

(c) $\lambda_1 + \lambda_2 + \lambda_3 = 0$ (d) $\lambda_3^2 = \lambda_1^2 + \lambda_2^2$

Ans. ***(b)***



Using Bohr's postulate for radiation of spectral line, we have

Radiation of wavelength from C to B

$$E_C - E_B = \frac{hc}{\lambda_1} \quad ...(i)$$

Radiation of wavelength from B to A

$$E_B - E_A = \frac{hc}{\lambda_2} \quad ...(ii)$$

Radiation of wavelength from C to A

$$E_C - E_A = \frac{hc}{\lambda_3} \quad ...(iii)$$

Also, $(E_C - E_A) = (E_C - E_B) + (E_B - E_A)$

$$\therefore \quad \frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$$

or $$\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

$$\Rightarrow \quad \lambda_3 = \frac{\lambda_1\lambda_2}{\lambda_1 + \lambda_2}$$

46 To explain his theory, Bohr used

[CBSE AIPMT 1989]

(a) conservation of linear momentum
(b) conservation of angular momentum
(c) conservation of quantum frequency
(d) conservation of energy

Ans. ***(b)***

According to Bohr, electron can revolve only in certain discrete non-radiating orbits, called stationary orbits, for which total angular momentum of the revolving electron is an integral multiple of $\dfrac{h}{2\pi}$,

where h is Planck's constant. For orbits, conservation of angular momentum is applicable.

$\therefore$ For any permitted orbit, $mvr = \dfrac{nh}{2\pi}$

47 The ionisation energy of hydrogen atom is 13.6 eV, the ionisation energy of helium atom would be

[CBSE AIPMT 1988]

(a) 13.6 eV (b) 27.2 eV
(c) 6.8 eV (d) 54.4 eV

Ans. ***(d)***

Ionisation energy is defined as the energy required to knock an electron completely out of an isolated gaseous atom. When electron is raised to the orbit $n = \infty$, it will be completely out of the atom.

Ionisation energy of helium,

$$E = \frac{2\pi^2 mZ^2 k^2 e^4}{h^2}\left[\frac{1}{1^2} - \frac{1}{\infty}\right]$$

$$= \frac{2\pi^2 m(2)^2 k^2 e^4}{h^2}\left[\frac{1}{1^2} - \frac{1}{\infty}\right]$$

Ionisation energy for hydrogen atom

$$= 13.6 \text{ eV} = \frac{2\pi^2 mk^2 e^2}{h^2} \times 4 \times \left[\frac{1}{1^2} - \frac{1}{\infty^2}\right]$$

$$= 4 \times 13.6 = 54.4 \text{ eV}$$

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27

Nuclei

TOPIC 1
Nucleus and Radioactivity

01 A radioactive nucleus ${}^{A}_{Z}X$ undergoes spontaneous decay in the sequence ${}^{A}_{Z}X \longrightarrow {}_{Z-1}B \longrightarrow {}_{Z-3}C \longrightarrow {}_{Z-2}D$, where Z is the atomic number of element X. The possible decay particles in the sequence are **[NEET 2021]**

(a) α, β^-, β^+ (b) α, β^+, β^-
(c) β^+, α, β^- (d) β^-, α, β^+

Ans. *(c)*

As we know that,

In α-decay, the atomic number is decreased by 2 units.

$$X^{A}_{Z} \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\text{He}$$

In β^+-decay, the atomic number is decreased by 1 unit.

$$X^{A}_{Z} \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + \bar{\nu}$$

In β^--decay, the atomic number is increased by 1 unit.

$$X^{A}_{Z} \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{\nu}$$

From the above relations, the spontaneous decay given in question can be written as

$$X^{A}_{Z} \xrightarrow{\beta^+} {}_{Z-1}B \xrightarrow{\alpha} {}_{Z-3}C \xrightarrow{\beta^-} {}_{Z-2}D$$

The possible decay particles in the sequence are β^+, α, β^-.

02 The half-life of a radioactive nuclide is 100 h. The fraction of original activity that will remain after 150 h would be **[NEET 2021]**

(a) $\frac{1}{2}$ (b) $\frac{1}{2\sqrt{2}}$ (c) $\frac{2}{3}$ (d) $\frac{2}{3\sqrt{2}}$

Ans. *(b)*

Given, the half-life of a radioactive nuclide, $t_{1/2} = 100$ h

As we know,

$$A = \frac{A_0}{2^{t/t_{1/2}}}$$

Here, A_0 is the original activity of the nuclide, A is the activity of the nuclide after time t.

$$\Rightarrow \frac{A}{A_0} = 2^{t/t_{1/2}} = 2^{-\frac{150}{100}}$$
$$= 2^{-3/2} = \frac{1}{2\sqrt{2}}$$

So, the fraction of original activity that will remain after 150 h will be $\frac{1}{2\sqrt{2}}$.

03 What happens to the mass number and atomic number of an element when it emits γ-radiation? **[NEET (Oct.) 2020]**

(a) Mass number decreases by four and atomic number decreases by two.
(b) Mass number and atomic number remain unchanged.
(c) Mass number remains unchanged, while atomic number decreases by one.
(d) Mass number increases by four and atomic number increases by two.

Ans. *(b)*

When an atom emits γ-radiation from its nucleus, then there is no change in its atomic number and mass number.

04 The half-life of a radioactive sample undergoing α-decay is 1.4×10^{17} s. If the number of nuclei in the sample is 2.0×10^{21}. The activity of the sample is nearly **[NEET (Oct.) 2020]**

(a) 10^4 Bq (b) 10^5 Bq
(c) 10^6 Bq (d) 10^3 Bq

Ans. *(a)*

Given, $T_{1/2} = 1.4 \times 10^{17}$ s

Number of nuclei in the sample,

$$N = 2.0 \times 10^{21}$$

$\therefore$ Activity of the sample $= \lambda N$

$$= \frac{0.693}{T_{1/2}} \times 2 \times 10^{21}$$
$$= \frac{0.693}{1.4 \times 10^{17}} \times 2 \times 10^{21}$$
$$= 0.99 \times 10^4$$
$$\simeq 1 \times 10^4 \text{ Bq} \simeq 10^4 \text{ Bq}$$

05 The rate of radioactive disintegration at an instant for a radioactive sample of half life 2.2×10^9 s is 10^{10} s^{-1}. The number of radioactive atoms in that sample at that instant is **[NEET (Odisha) 2019]**

(a) 3.17×10^{20} (b) 3.17×10^{17}
(c) 3.17×10^{18} (d) 3.17×10^{19}

Ans. *(d)*

Given, half life $T_{1/2} = 2.2 \times 10^9$ s

Rate of disintegration, $R = 10^{10}$ s^{-1}

If N be the number of nuclei present, then the rate of disintegration is

$$\frac{dN}{dt} = \lambda N \qquad (\lambda = \text{decay constant})$$

$$\Rightarrow \quad R = \lambda N \quad \text{or} \quad N = \frac{R}{\lambda} \qquad \ldots(i)$$

Also, the half life is given by,

$$T_{1/2} = \frac{0.693}{\lambda}$$

$$\Rightarrow \quad \lambda = \frac{0.693}{T_{1/2}} \qquad \ldots(ii)$$

From Eq. (i) and (ii), we get

$$N = \frac{R}{0.693} \times T_{1/2}$$
$$= \frac{10^{10} \times 2.2 \times 10^9}{0.693}$$
$$= 3.17 \times 10^{19}$$

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06 α-particle consists of **[NEET (National) 2019]**

(a) 2 electrons, 2 protons and 2 neutrons
(b) 2 electrons and 4 protons only
(c) 2 protons only
(d) 2 protons and 2 neutrons only

Ans. *(d)*

α-particles are doubly ionised helium nucleus (He^{2+}) which are emitted in any radioactive process. So, they have two protons, 2 neutrons in its nucleus and no electron.

07 For a radioactive material, half-life is 10 minutes. If initially there are 600 number of nuclei, the time taken (in minutes) for the disintegration of 450 nuclei is **[NEET 2018]**

(a) 30 (b) 10 (c) 20 (d) 15

Ans. *(c)*

Key Concept *After n half-life, the number of nuclei left undecayed is given as*

$$N = N_0\left(\frac{1}{2}\right)^n$$

where, $n = \frac{t}{t_{1/2}}$

Here, initially number of nuclei, $N_0 = 600$

After disintegration, number of nuclei, $N' = 450$

∴ Number of nuclei left undecayed,

$$N = N_0 - N'$$
$$= 600 - 450 = 150$$

Half-life, $t_{1/2} = 10$ min

As, $\frac{N}{N_0} = \left(\frac{1}{2}\right)^{t/t_{1/2}}$

Substituting the given values, we get

$$\frac{150}{600} = \left(\frac{1}{2}\right)^{t/20}$$

or $\frac{1}{4} = \left(\frac{1}{2}\right)^{t/10}$

or $\left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^{t/10}$

or $\frac{t}{10} = 2 \Rightarrow t = 20$ min

08 Radioactive material *A* has decay constant 8λ and material *B* has decay constant λ. Initially, they have same number of nuclei. After what time, the ratio of number of nuclei of material *B* to that *A* will be $\frac{1}{e}$? **[NEET 2017]**

(a) $\frac{1}{\lambda}$ (b) $\frac{1}{7\lambda}$
(c) $\frac{1}{8\lambda}$ (d) $\frac{1}{9\lambda}$

Ans. *(b)*

Let initial number of nuclei in *A* and *B* is N_0.

Number of nuclei of *A* after time *t* is

$$N_A = N_0 e^{-8\lambda t} \quad ...(i)$$

Similarly, number of nuclei of *A* after time *t* is

$$N_B = N_0 e^{-\lambda t} \quad ...(ii)$$

It is given that $\frac{N_A}{N_B} = \frac{1}{e}$ $[\because N_B > N_A]$

Now, from Eqs. (i) and (ii)

$$\frac{e^{-8\lambda t}}{e^{-\lambda t}} = \frac{1}{e}$$

Rearranging

$\Rightarrow$ $e^{-1} = e^{-7\lambda t} \Rightarrow 7\lambda t = 1$

$\Rightarrow$ Time $t = \frac{1}{7\lambda}$

09 The half-life of a radioactive substance is 30 minutes. The time (in minutes) taken between 40% decay and 85% decay of the same radioactive substance is **[NEET 2016]**

(a) 15 (b) 30 (c) 45 (d) 60

Ans. *(d)*

Key Idea Half-life of a radioactive substance is $T_{1/2} \propto \log\left(\frac{N_0}{N}\right)$

Given, $N_1 = 0.6N_0$ (∵40% decay)

$N_2 = 0.15N_0$ (∵85% decay)

Putting these in the formula,

$$\frac{N_2}{N_1} = \frac{0.15N_0}{0.6N_0} = \frac{1}{4} = \left(\frac{1}{4}\right)^2$$

So, two half-life periods has passed.

Thus, time taken $= 2 \times t_{1/2} = 2 \times 30 = 60$ min

10 If radius of the $^{27}_{13}$Al nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}$Te nucleus is nearly **[CBSE AIPMT 2015]**

(a) $\left(\frac{53}{13}\right)^{\frac{1}{3}} R_{Al}$ (b) $\frac{5}{3}R_{Al}$
(c) $\frac{3}{5}R_{Al}$ (d) $\left(\frac{13}{53}\right)^{\frac{1}{3}} R_{Al}$

Ans. *(b)*

Radius of the nucleus is given by

$$R = R_0 A^{1/3} \Rightarrow R \propto A^{1/3}$$

$$\frac{R_{Al}}{R_{Te}} = \left(\frac{A_{Al}}{A_{Te}}\right)^{1/3} = \left(\frac{27}{125}\right)^{1/3} = \frac{3}{5}$$

$$R_{Te} = \frac{5}{3}R_{Al}$$

11 A radio isotope *X* with a half life 1.4×10^9 yr decays of *Y* which is stable. A sample of the rock from a cave was found to contain *X* and *Y* in the ratio 1 : 7. The age of the rock is **[CBSE AIPMT 2014]**

(a) 1.96×10^9 yr (b) 3.92×10^9 yr
(c) 4.20×10^9 yr (d) 8.40×10^9 yr

Ans. *(c)*

Ratio of *X* : *Y* is given = 1 : 7

$$\frac{m_x}{m_y} = \frac{1}{7} \Rightarrow 7m_x = m_y$$

Let the initial total mass be *m*.

$\Rightarrow$ $m_x + m_y = m \Rightarrow \frac{m_y}{7} + m_y = m$

$\Rightarrow$ $\frac{8m_y}{7} = m \Rightarrow m_y = \frac{7}{8}m$

only $\frac{1}{8}$ part remains

$\Rightarrow$ $1 \xrightarrow{T_{1/2}} \frac{1}{2} \xrightarrow{T_{1/2}} \frac{1}{4} \xrightarrow{T_{1/2}} \frac{1}{8}$

So, time taken to become $\frac{1}{8}$ unstable part

$$= 3 \times T_{1/2} = 3 \times 1.4 \times 10^9 = 4.2 \times 10^9 \text{ y}$$

Alternative

$$\underset{\text{Active}}{X} \rightarrow \underset{\text{Stable}}{Y}$$

As we know that

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$$

$$\frac{1}{1+7} = \frac{1}{8} = \left(\frac{1}{2}\right)^3 \Rightarrow n = 3$$

As $T_{1/2} = \frac{t}{n}$

∴ $t = T_{1/2} \times n$

$$= 1.4 \times 10^9 \times 3 = 4.2 \times 10^9 \text{ y}$$

12 The half-life of a radioactive isotope *X* is 20 yr. It decays to another element *Y* which is stable. The two elements *X* and *Y* were found to be in the ratio 1 : 7 in a sample of a given rock. The age of the rock is estimated to be **[NEET 2013]**

(a) 40 yr (b) 60 yr (c) 80 yr (d) 100 yr

Ans. *(b)*

As we know that

$$N = N_0\left(\frac{1}{2}\right)^n$$

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$$\frac{N}{N_0}=\left(\frac{1}{2}\right)^3=\frac{1}{1+7}=\frac{1}{8}$$

So, number of half lifes = 3

$\Rightarrow \quad T=20\,\text{yr}$

$\therefore \quad T=\frac{t}{n}$

$\Rightarrow \quad t=T\,n=20\times3\,\text{yr}=60\text{yr}$

13 A mixture consists of two radioactive materials A_1 and A_2 with half lives of 20 s and 10 s respectively. Initially the mixture has 40 g of A_1 and 160 g of A_2. The amount of the two in the mixture will become equal after **[CBSE AIPMT 2012]**

(a) 60 s (b) 80 s
(c) 20 s (d) 40 s

Ans. *(d)*

For 40 g amount,

$$40\text{ g}\xrightarrow[\text{half-life}]{20\text{ s}}20\text{ g}\xrightarrow{20\text{ s}}10\text{ g}$$

For 160 g amount,

$$160\text{ g}\xrightarrow{10\text{ s}}80\text{ g}\xrightarrow{10\text{ s}}40\text{ g}\xrightarrow{10\text{ s}}20\text{ g}\xrightarrow{10\text{ s}}10\text{ g}$$

So, after 40 s A_1 and A_2 will become equal.

14 A radioactive nucleus of mass M emits a photon of frequency ν and the nucleus recoils. The recoil energy will be **[CBSE AIPMT 2011]**

(a) $h^2\nu^2/2Mc^2$ (b) zero
(c) $h\nu$ (d) $Mc^2-h\nu$

Ans. *(a)*

Momentum of a photon

$$p=\frac{h\nu}{c}$$

Hence, recoil energy, $E=\frac{p^2}{2M}$

$$\therefore \quad E=\frac{\left(\frac{h\nu}{c}\right)^2}{2M}\ \text{or}\ E=\frac{h^2\nu^2}{2Mc^2}$$

15 The half-life of a radioactive isotope X is 50 yr. It decays to another element Y which is stable. The two elements X and Y were found to be in the ratio of 1 : 15 in a sample of a given rock. The age of the rock was estimated to be **[CBSE AIPMT 2011]**

(a) 200 yr (b) 250 yr
(c) 100 yr (d) 150 yr

Ans. *(a)*

We know that

$$\frac{N}{N_0}=\left(\frac{1}{2}\right)^n=\left(\frac{1}{2}\right)^{t/T_{1/2}}$$

$$\Rightarrow \frac{1}{1+15}=\frac{1}{16}=\left(\frac{1}{2}\right)^4=\left(\frac{1}{2}\right)^{t/50}$$

$$t=4\times50$$

$$t=200\,\text{yr}$$

16 A nucleus ${}^{m}_{n}X$ emits one α-particle and two β^- particles. The resulting nucleus is **[CBSE AIPMT 2011]**

(a) ${}^{m-6}_{n}Z$ (b) ${}^{m-4}_{n}X$ (c) ${}^{m-4}_{n-2}Y$ (d) ${}^{m-6}_{n-4}Z$

Ans. *(b)*

$${}^{m}_{n}X\xrightarrow{\alpha}{}_{n-2}X^{m-4}\xrightarrow{2\beta}{}_{n}X^{m-4}$$

17 The activity of a radioactive sample is measured as N_0 counts per minute at $t=0$ and N_0/e counts per minute at $t=5$ min. The time (in minute) at which the activity reduces to half its value is **[CBSE AIPMT 2010]**

(a) $\log_e 2/5$ (b) $\frac{5}{\log_e 2}$
(c) $5\log_{10}2$ (d) $5\log_e 2$

Ans. *(d)*

Fraction remains after n half lives

$$\frac{N}{N_0}=\left(\frac{1}{2}\right)^n=\left(\frac{1}{2}\right)^{t/T}$$

Given $N=\frac{N_0}{e}\Rightarrow\frac{N_0}{eN_0}=\left(\frac{1}{2}\right)^{5/T}$

or $\frac{1}{e}=\left(\frac{1}{2}\right)^{5/T}$

Taking log on both sides, we get

$$\log 1-\log e=\frac{5}{T}\log\frac{1}{2}$$

$$-1=\frac{5}{T}(-\log 2)$$

$$\Rightarrow \quad T=5\log_e 2$$

Now, let t' be the time after which activity reduces to half

$$\left(\frac{1}{2}\right)=\left(\frac{1}{2}\right)^{t'/5\log_e 2}\Rightarrow t'=5\log_e 2$$

18 The number of beta particles emitted by a radioactive substance is twice the number of alpha particles emitted by it. The resulting daughter is an **[CBSE AIPMT 2009]**

(a) isobar of parent
(b) isomer of parent
(c) isotone of parent
(d) isotope of parent

Ans. *(d)*

Let the radioactive substance be ${}^{A}_{Z}X$.

Radioactive transition is given by

$${}^{A}_{Z}X\xrightarrow{-\alpha}{}^{A-4}_{Z-2}X\xrightarrow{-2\beta}{}^{A-4}_{Z}X$$

The atoms of element having same atomic number but different mass numbers are called isotopes.

So, ${}^{A}_{Z}X$ and ${}^{A-4}_{Z}X$ are isotopes.

19 In the nuclear decay given below

$${}^{A}_{Z}X\longrightarrow{}^{A}_{Z+1}Y\longrightarrow{}^{A-4}_{Z-1}B^{*}\longrightarrow{}^{A-4}_{Z-1}B$$

the particles emitted in the sequence are **[CBSE AIPMT 2009]**

(a) β,α,γ (b) γ,β,α
(c) β,γ,α (d) α,β,γ

Ans. *(a)*

Alpha particles are positively charged particles with charge $+2e$ and mass $4\,m$. Emission of an α-particle reduces the mass of the radionuclide by 4 and its atomic number by 2. β-particles are negatively charged particles with rest mass as well as charge same as that of electrons. γ-particles carry no charge and mass.

Radioactive transition will be as follows

$${}^{A}_{Z}X\longrightarrow{}^{A}_{Z+1}Y+\beta^0_{-1}$$

$${}^{A}_{Z+1}Y\longrightarrow{}^{A-4}_{Z-1}\beta+\alpha^4_2$$

$${}^{A-4}_{Z+1}\beta\longrightarrow{}^{A-4}_{Z-1}\beta+\gamma^0_0$$

20 Two radioactive materials X_1 and X_2 have decay constants 5λ and λ respectively. If initially they have the same number of nuclei, then the ratio of the number of nuclei of X_1 to that of X_2 will be $\frac{1}{e}$ after a time **[CBSE AIPMT 2008]**

(a) λ (b) $\frac{1}{2}\lambda$ (c) $\frac{1}{4\lambda}$ (d) $\frac{e}{\lambda}$

Ans. *(c)*

$$N_1=N_0e^{-5\lambda t}\quad\ldots(i)$$

$$N_2=N_0e^{-\lambda t}\quad\ldots(ii)$$

Dividing Eq. (i) by Eq. (ii), we obtain

$$\frac{N_1}{N_2}=\frac{1}{e}$$

$$=\frac{e^{-5\lambda t}}{e^{-\lambda t}}=e^{-4\lambda t}$$

$$\therefore \quad e^{-1}=e^{-4\lambda t}$$

$$1=4\lambda t$$

or $\quad t=\frac{1}{4\lambda}$

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21 Two radioactive substances A and B have decay constants 5λ and λ respectively. At $t = 0$ they have the same number of nuclei. The ratio of number of nuclei of A to those of B will be $\left(\frac{1}{e}\right)^2$ after a time interval **[CBSE AIPMT 2007]**

(a) $\frac{1}{4\lambda}$ (b) 4λ (c) 2λ (d) $\frac{1}{2\lambda}$

Ans. *(d)*

Number of nuclei remained after time t can be written as

$$N = N_0 e^{-\lambda t}$$

where, N_0 is initial number of nuclei of both the substances.

$$N_1 = N_0 e^{-5\lambda t} \quad ...(i)$$

and $$N_2 = N_0 e^{-\lambda t} \quad ...(ii)$$

Dividing Eq. (i) by Eq. (ii), we obtain

$$\frac{N_1}{N_2} = e^{(-5\lambda + \lambda)t} = e^{-4\lambda t} = \frac{1}{e^{4\lambda t}}$$

But, we have given

$$\frac{N_1}{N_2} = \left(\frac{1}{e}\right)^2 = \frac{1}{e^2}$$

Hence, $$\frac{1}{e^2} = \frac{1}{e^{4\lambda t}}$$

Comparing the powers, we get

$$2 = 4\lambda t \quad \text{or} \quad t = \frac{2}{4\lambda} = \frac{1}{2\lambda}$$

22 If the nucleus $^{27}_{13}Al$ has a nuclear radius of about 3.6 fm, then $^{125}_{52}Te$ would have its radius approximately as **[CBSE AIPMT 2007]**

(a) 6.0 fm (b) 9.6 fm
(c) 12.0 fm (d) 4.8 fm

Ans. *(a)*

If R is the radius of the nucleus, the corresponding volume $\frac{4}{3}\pi R^3$ has been found to be proportional to A.

This relationship is expressed in inverse form as

$$R = R_0 A^{1/3}$$

The value of R_0 is 1.2×10^{-15} m, i.e. 1.2 fm

Therefore, $$\frac{R_{Al}}{R_{Te}} = \frac{R_0 (A_{Al})^{1/3}}{R_0 (A_{Te})^{1/3}}$$

$$\frac{R_{Al}}{R_{Te}} = \frac{(A_{Al})^{1/3}}{(A_{Te})^{1/3}}$$

$$= \frac{(27)^{1/3}}{(125)^{1/3}} = \frac{3}{5}$$

or $$R_{Te} = \frac{5}{3} \times R_{Al}$$

$$= \frac{5}{3} \times 3.6 = 6 \text{ fm}$$

23 In radioactive decay process, the negatively charged emitted β-particles are **[CBSE AIPMT 2007]**

(a) the electrons present inside the nucleus
(b) the electrons produced as a result of the decay of neutrons inside the nucleus
(c) the electrons produced as a result of collisionsbetween atoms
(d) the electrons orbiting around the nucleus

Ans. *(b)*

Beta decay involves the emission of either electrons or positrons. The electrons or positrons emitted in a β-decay do not exist inside the nucleus. They are only created at the time of emission, just as photons are created when an atom makes a transition from higher to a lower energy state.

In negative β-decay, a neutron in the nucleus is transformed into a proton, an electron and an antineutrino. Hence, in radioactive decay process, the negatively charged emitted β-particles are the electrons produced as a result of the decay of neutrons present inside the nucleus.

24 The radius of germanium (Ge) nuclide is measured to be twice the radius of $^{9}_{4}Be$. The number of nucleons in Ge are **[CBSE AIPMT 2006]**

(a) 73 (b) 74
(c) 75 (d) 72

Ans. *(d)*

According to question, radius of $^{9}_{4}Be$ nucleus be r, and radius of germanium (Ge) nucleus will be $2r$.

Radius of a nucleus is given by

$$R = R_0 A^{1/3}$$

R = Radius of atom having mass number. A

$$R \propto A^{1/3}$$

So, $$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3}$$

$$\Rightarrow \quad \frac{r}{2r} = \left(\frac{9}{A_2}\right)^{1/3} \qquad (\because A_1 = 9)$$

or $$\left(\frac{1}{2}\right)^3 = \frac{9}{A_2}$$

Hence, $$A_2 = 9 \times (2)^3$$

$$= 9 \times 8 = 72$$

Thus, in germanium (Ge) nucleus number of nucleons is 72.

25 In a radioactive material the activity at time t_1 is R_1 and at a later time t_2, it is R_2. If the decay constant of the material is λ, then **[CBSE AIPMT 2006]**

(a) $R_1 = R_2 e^{-\lambda (t_1 - t_2)}$

(b) $R_1 = R_2 e^{\lambda (t_1 - t_2)}$

(c) $R_1 = R_2 \left(\frac{t_2}{t_1}\right)$

(d) $R_1 = R_2$

Ans. *(a)*

The decay rate R of a radioactive material is the number of decays per second.

From radioactive decay law,

$$-\frac{dN}{dt} \propto N$$

or $$-\frac{dN}{dt} = \lambda N$$

i.e. Rate of reaction is directly proportional to the initial concentration of reactants.

Thus, $$R = -\frac{dN}{dt} \quad \text{or} \quad R \propto N$$

or $$R = \lambda N \quad \text{or} \quad R = \lambda N_0 e^{-\lambda t} \quad ...(i)$$

where $R_0 = \lambda N_0$ is the activity of the radioactive material at time $t = 0$.

At time t_1, $R_1 = R_0 e^{-\lambda t_1}$ ...(ii)

At time t_2 $R_2 = R_0 e^{-\lambda t_2}$ ...(iii)

Dividing Eq. (ii) by Eq. (iii), we have

$$\frac{R_1}{R_2} = \frac{e^{-\lambda t_1}}{e^{-\lambda t_2}} = e^{-\lambda (t_1 - t_2)}$$

or $$R_1 = R_2 e^{-\lambda (t_1 - t_2)}$$

26 The nuclei of which one of the following pairs of nuclei are isotones ? **[CBSE AIPMT 2005]**

(a) $_{34}Se^{74}, _{31}Ga^{71}$ (b) $_{42}Mo^{92}, _{40}Zr^{92}$
(c) $_{38}Sr^{84}, _{38}Sr^{86}$ (d) $_{20}Ca^{40}, _{16}S^{32}$

Ans. *(a)*

The nuclei which have same number of neutrons but different atomic number and mass number are known as isotones. In choice (a) nuclei of $_{34}Se^{74}$ and $_{31}Ga^{71}$ are isotones as

$$A - Z = 74 - 34 = 71 - 31 = 40$$

27 The half-life of radium is about 1600 yr. Of 100 g of radium existing now, 25 g will remain unchanged after **[CBSE AIPMT 2004]**

(a) 4800 yr (b) 6400 yr
(c) 2400 yr (d) 3200 yr

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Ans. *(d)*

Amount of substance remained is

$$M = M_0\left(\frac{1}{2}\right)^n \qquad \begin{bmatrix} M = \text{substance remained} \\ M_0 = \text{initial amount} \end{bmatrix}$$

Given, $M_0 = 100\,\text{g}$, $M = 25\,\text{g}$,

Half-life of radioactive substance $T_{1/2} = 1600\,\text{yr}$

So, $$25 = 100\left(\frac{1}{2}\right)^n$$

or $$\frac{25}{100} = \left(\frac{1}{2}\right)^n \text{ or } \left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^n$$

Comparing the power, we have

$$n = 2$$

or $$\frac{t}{T_{1/2}} = 2$$

or $t = 2T_{1/2} = 2 \times 1600 = 3200\,\text{yr}$

28 A sample of radioactive element has a mass of 10 g at an instant $t = 0$. The approximate mass of this element in the sample after two mean lives is **[CBSE AIPMT 2003]**

(a) 3.70 g (b) 6.30 g
(c) 1.35 g (d) 2.50 g

Ans. *(c)*

Mean life of radioactive substance is given by

$$\tau = \frac{1}{\lambda}, (\lambda \text{ is decay constant})$$

Also, it is given that $t = 2\tau$

So, $$t = 2 \times \frac{1}{\lambda} = \frac{2}{\lambda}$$

Thus, mass remained after time t is

$$M = M_0\, e^{-\lambda t} \qquad \begin{bmatrix} M = \text{Final mass} \\ M_0 = \text{Inital mass} \\ \lambda = \text{Decay constant} \end{bmatrix}$$

$$= 10\, e^{-\lambda \times \frac{2}{\lambda}} \qquad (\because M_0 = 10\,\text{g})$$

$$= 10\, e^{-2}$$

$$= \frac{10}{e^2}$$

$$= 1.35\,\text{g}$$

29 A nuclear reaction given by

$${}_ZX^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + \bar{\nu}$$

represents **[CBSE AIPMT 2003]**

(a) fusion (b) fission
(c) β-decay (d) γ-decay

Ans. *(c)*

Since in the given reaction ${}_{-1}e^0$ and antineutrino $(\bar{\nu})$ are released, so it can be considered β-decay.

30 The mass number of a nucleus is **[CBSE AIPMT 2003]**

(a) sometimes equal to its atomic number
(b) sometimes less than and sometimes more than its atomic number
(c) always less than its atomic number
(d) always more than its atomic number

Ans. *(a)*

Mass number

= No. of protons + No. of neutrons

For example, in case of hydrogen

Number of neutrons = 0

Thus, mass number = atomic number

Hence, sometimes the atomic number is equal to the mass number.

31 The volume occupied by an atom is greater than the volume of the nucleus by factor of about **[CBSE AIPMT 2003]**

(a) 10^{10} (b) 10^{15} (c) 10^{1} (d) 10^{5}

Ans. *(b)*

Order of Radius of atom $\approx 10^{-10}\,\text{m}$

Order of Radius of nucleus $\approx 10^{-15}\,\text{m}$

Ratio of volume of atom to volume of nucleus

$$= \frac{\text{volume of atom}}{\text{volume of nucleus}} = \frac{\frac{4}{3}\pi r_1^3}{\frac{4}{3}\pi r_2^3}$$

$$= \left(\frac{10^{-10}}{10^{-15}}\right)^3 = 10^{15}$$

32 A sample of radioactive elements contains 4×10^{10} active nuclei. If half-life of element is 10 days, then the number of decayed nuclei after 30 days is **[CBSE AIPMT 2002]**

(a) 0.5×10^{10} (b) 2×10^{10}
(c) 3.5×10^{10} (d) 1×10^{10}

Ans. *(c)*

Number of half-lives

$$n = \frac{t}{T_{1/2}} = \frac{30\text{ days}}{10\text{ days}} = 3$$

$[T_{1/2} = \text{half life period}]$

So, number of undecayed radioactive nuclei is given by

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n \qquad \begin{bmatrix} N = \text{Final number} \\ N_0 = \text{Initial number} \end{bmatrix}$$

or $$N = N_0\left(\frac{1}{2}\right)^n = 4 \times 10^{10}\left(\frac{1}{2}\right)^3$$

$$= 4 \times 10^{10} \times \frac{1}{8} = 0.5 \times 10^{10}$$

Thus, number of nuclei decayed after 30 days

$$= N_0 - N$$

$$= 4 \times 10^{10} - 0.5 \times 10^{10} = 3.5 \times 10^{10}$$

33 In compound $X(n,\alpha) \rightarrow {}_3\text{Li}^7$, the element X is **[CBSE AIPMT 2001]**

(a) ${}_2\text{He}^4$ (b) ${}_5\text{B}^{10}$ (c) ${}_5\text{B}^{9}$ (d) ${}_4\text{Be}^{11}$

Ans. *(b)*

The given nuclear reaction can be written as

$${}_ZX^A + {}_0n^1 \longrightarrow {}_3\text{Li}^7 + {}_2\text{He}^4$$

Conservation of mass number gives,

$$A + 1 = 7 + 4 \Rightarrow A = 10$$

Conservation of charge number/Atomic No. gives,

$$Z + 0 = 2 + 3 \Rightarrow Z = 5$$

Hence, $Z = 5$, $A = 10$ corresponds to boron $({}_5\text{B}^{10})$.

34 Half-life of a radioactive substance is 12.5 h and its mass is 256 g. After what time, the amount of remaining substance is 1g ? **[CBSE AIPMT 2001]**

(a) 75 h (b) 100 h (c) 125 h (d) 150 h

Ans. *(b)*

The mass of radioactive substance remained is,

$$M = M_0\left(\frac{1}{2}\right)^n$$

Here, final mass, $M = 1$ g, initial mass, $M_0 = 256$ g, half life period, $T_{1/2} = 12.5$ h

So, $$1 = 256\left(\frac{1}{2}\right)^n \text{ or } \frac{1}{256} = \left(\frac{1}{2}\right)^n$$

or $$\left(\frac{1}{2}\right)^8 = \left(\frac{1}{2}\right)^n$$

Comparing the powers on both the sides, we get

$$n = 8 = \frac{t}{T_{1/2}}$$

$\therefore$ $$t = 8T_{1/2} = 8 \times 12.5 = 100\,\text{h}$$

35 Half-life period of a radioactive substance is 6 h. After 24 h activity is 0.01 μC, what was the initial activity ? **[CBSE AIPMT 2001]**

(a) 0.04 μC (b) 0.08 μC (c) 0.24 μC (d) 0.16 μC

Ans. *(d)*

The activity of a radioactive substance is

$$R = R_0\left(\frac{1}{2}\right)^n \qquad \begin{bmatrix} R = \text{Final number} \\ R_0 = \text{Initial number} \end{bmatrix}$$

Here, n = number of half-lives

$$= \frac{t}{T_{1/2}} = \frac{24}{6} = 4 \quad [T_{1/2} = \text{Half life period}]$$

and $R = 0.01\,\mu\text{C}$

So, $$0.01 = R_0\left(\frac{1}{2}\right)^4$$

or $$R_0 = 0.01 \times (2)^4$$

$$= 0.01 \times 16 = 0.16\,\mu\text{C}$$

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36 Which of the following is positively charged ? **[CBSE AIPMT 2001]**

(a) α-particle (b) β-particle
(c) γ-rays (d) X-rays

Ans. *(a)*

Out of the given choices, X-rays and γ-rays are electromagnetic waves, so they have no charge. β-particles are negatively charged particles and are fast moving electrons. Alpha (α) particles have positive charge and is a nucleus of helium.

37 A nuclear decay is expressed as

$${}_6C^{11} \longrightarrow {}_5B^{11} + \beta^+ + X$$

Then the unknown particle X is **[CBSE AIPMT 2000]**

(a) neutron (b) antineutrino
(c) proton (d) neutrino

Ans. *(d)*

Let Z be the charge number and A be the mass number of particle X, then conservation of charge number gives

$$6 = 5 + 1 + Z \Rightarrow Z = 0$$

Conservation of mass number gives,

$$11 = 11 + 0 + A \Rightarrow A = 0$$

X is a particle of zero charge and zero mass. This particle may be neutrino or antineutrino. As we know that for positive β-particle, neutrino is emitted and with negative β-particle, antineutrino is emitted.

Thus, in this case neutrino will be emitted.

38 The half-life of a radioactive material is 3 h. If the initial amount is 300 g, then after 18 h, it will remain **[CBSE AIPMT 2000]**

(a) 4.68 g (b) 46.8 g
(c) 9.375 g (d) 93.75 g

Ans. *(a)*

Number of half-lives

$$n = \frac{t}{T_{1/2}} = \frac{18}{3} = 6 \quad [T_{1/2} = \text{half life period}]$$

Amount remained after n half-lives

$$N = N_0\left(\frac{1}{2}\right)^n \quad \begin{bmatrix} N_0 = \text{initial count} \\ N = \text{final count} \end{bmatrix}$$

Given, $N_0 = 300$ g

$$\therefore \quad N = 300\left(\frac{1}{2}\right)^6 = 300 \times \frac{1}{64} = 4.68 \text{ g}$$

Alternative

Total time of decay given

$$t = \frac{2.303}{\lambda}\log_{10}\left(\frac{300}{N}\right)$$

but $$\lambda = \frac{0.693}{T} = \frac{0.693}{3} = 0.231/\text{h}$$

$$\therefore \quad t = \frac{2.303}{0.231}\log_{10}\left(\frac{300}{N}\right)$$

Given, $t = 18$ h

So, $$18 = \frac{2\ .303}{0\ .231}\log_{10}\left(\frac{300}{N}\right)$$

or $$\log_{10}\left(\frac{300}{N}\right) = \frac{0.231}{2.303} \times 18$$

or $$\frac{300}{N} = (10)^{1.8}$$

or $$N = \frac{300}{(10)^{1.8}} = 4.68 \text{ g}$$

39 The relationship between disintegration constant (λ) and half-life (T) will be **[CBSE AIPMT 2000]**

(a) $\lambda = \dfrac{\log_{10} 2}{T}$ (b) $\lambda = \dfrac{\log_e 2}{T}$

(c) $\lambda = \dfrac{T}{\log_e 2}$ (d) $\lambda = \dfrac{\log_2 e}{T}$

Ans. *(b)*

The time required for the number of parent nuclei to fall to 50% is called half-life T and may be related to disintegration constant λ as follows. Since,

$$0.5N_0 = N_0\, e^{-\lambda T}$$

$$\begin{bmatrix} N = \text{Final No. of nuclei} \\ = 0.5N_0 \\ \lambda = \text{decay constant} \end{bmatrix}$$

N_0 = Initial No. of nuclei

λ = decay constant

we have, $$\lambda T = \log_e 2$$

$$\therefore \quad \lambda = \frac{\log_e 2}{T}$$

40 In one α and 2 β-emissions **[CBSE AIPMT 1999]**

(a) mass number reduces by 2
(b) mass number reduces by 6
(c) atomic number reduces by 2
(d) atomic number remains unchanged

Ans. *(d)*

The α-particle can be represented as ${}_2He^4$ and β-particle as ${}_{-1}\beta^0$. So, after emission of one

α-particle the mass number of resultant nucleus decreases by 4 unit and atomic number by 2 unit. Similarly, after emission of one β-particle the atomic number increases by 1 unit keeping its mass number same. So, according to reaction (assuming ${}_ZX^A$ the initial nucleus)

$${}_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 \quad (\alpha\text{-particle})$$

and ${}_{Z-2}Y^{A-4} \rightarrow {}_ZX^{A-4} + 2({}_{-1}\beta^0)$ (2 β-particles)

So, by one α and two β-emissions the atomic number remains unchanged. i.e. formation of isotopes takes place.

41 Alpha particles are **[CBSE AIPMT 1999]**

(a) 2 free protons
(b) helium atoms
(c) singly ionised helium atoms
(d) doubly ionised helium atoms

Ans. *(d)*

Alpha particle is a positive particle. An alpha particle has 3.2×10^{-19} C charge twice the negative charge of an electron. The mass of an α-particle is 6.645×10^{-27} kg which is equal to mass of helium nucleus. When two electrons are emitted by a helium atom, a nucleus of helium remains which has charge equal to that of two electrons. Actually alpha (α) particle is a nucleus of helium. Hence, it is also called as doubly-ionised helium atom.

42 A nucleus ${}_nX^m$ emits one α and two β-particles. The resulting nucleus is **[CBSE AIPMT 1998]**

(a) ${}_nX^{m-4}$ (b) ${}_{n-2}Y^{m-4}$
(c) ${}_{n-4}Z^{m-4}$ (d) None of these

Ans. *(a)*

The reaction can be shown as

$${}_nX^m \xrightarrow{\alpha\,({}_2He^4)} {}_{n-2}Y^{m-4}$$

$${}_{n-2}Y^{m-4} \xrightarrow{2\,({}_{-1}\beta^0)} {}_nX^{m-4}$$

Thus, the resulting nucleus is the isotope of parent nucleus and is ${}_nX^{m-4}$.

43 Atomic weight of boron is 10.81 and it has two isotopes ${}^{10}_5B$ and ${}^{11}_5B$. Then, the ratio of atoms of ${}^{10}_5B$ and ${}^{11}_5B$ in nature would be **[CBSE AIPMT 1998]**

(a) 19 : 81 (b) 10 : 11 (c) 15 : 16 (d) 81 : 19

Ans. *(a)*

Let n_1 and n_2 be the number of atoms in ${}^{10}_5B$ and ${}^{11}_5B$ isotopes.

Atomic weight

$$= \frac{n_1 \times (\text{At. wt. of } {}^{10}_5B) + n_2 \times (\text{At. wt. of } {}^{11}_5B)}{n_1 + n_2}$$

or $$10.81 = \frac{n_1 \times 10 + n_2 \times 11}{n_1 + n_2}$$

or $$10.81\, n_1 + 10.81\, n_2 = 10\, n_1 + 11\, n_2$$

or $$0.81\, n_1 = 0.19\, n_2$$

or $$\frac{n_1}{n_2} = \frac{0.19}{0.81} = \frac{19}{81}$$

Note

Atomic weight of an atom having two or more isotopes is the average of the total weight of two of more isotopes

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44 Half-lives of two radioactive substances *A* and *B* are respectively 20 min and 40 min. Initially, the samples of *A* and *B* have equal number of nuclei. After 80 min the ratio of remaining number of *A* and *B* nuclei is **[CBSE AIPMT 1998]**

(a) 1 : 16 (b) 4 : 1 (c) 1 : 4 (d) 1 : 1

Ans. *(c)*

Total time given = 80 min

Number of half-lives of

$$A,\ n_A = \frac{80\ \text{min}}{20\ \text{min}} = 4$$

Number of half-lives of

$$B,\ n_B = \frac{80\ \text{min}}{40\ \text{min}} = 2$$

Number of nuclei remained undecayed

$$N = N_0\left(\frac{1}{2}\right)^n$$

where N_0 is initial number of nuclei and N is final number of nuclei

So for two different cases (A) and (B),

$$\frac{N_A}{N_B} = \frac{\left(\frac{1}{2}\right)^{n_A}}{\left(\frac{1}{2}\right)^{n_B}} \quad \text{or} \quad \frac{N_A}{N_B} = \frac{\left(\frac{1}{2}\right)^4}{\left(\frac{1}{2}\right)^2} = \frac{\left(\frac{1}{16}\right)}{\left(\frac{1}{4}\right)}$$

or $\frac{N_A}{N_B} = \frac{1}{4}$

45 A free neutron decays into a proton, an electron and **[CBSE AIPMT 1997]**

(a) a beta particle (b) an alpha particle

(c) an antineutrino (d) a neutrino

Ans. *(c)*

Pauli suggested that after emission of β-particle (electron) a neutron is converted into a proton in a nucleus and in this reaction an electron and an antineutrino ($\bar{\nu}$) will be formed. This reaction is represented as

$$\underset{\text{(Neutron)}}{{}_0n^1} \rightarrow \underset{\text{(Proton)}}{{}_1H^1} + \underset{\text{(Electron)}}{{}_{-1}\beta^0} + \underset{\text{(Antineutrino)}}{\bar{\upsilon}}$$

Antineutrino is a particle whose mass is negligible and on which no charge is present.

After emission of β-particle, the total number of particles (mass-number) in a nucleus remains unchanged but no. of neutrons reduces by 1 making the no. of protons (i.e. charge-number) to increase by 1.

46 The stable nucleus that has a radius half that of Fe^{56} is **[CBSE AIPMT 1997]**

(a) Li^7 (b) Na^{21} (c) S^{16} (d) Ca^{40}

Ans. *(a)*

The relation between nuclei radius (R) and mass number (A) is given by

$$R \propto A^{1/3} \quad \text{...(i)}$$

or $A \propto R^3$

or $\frac{A_1}{A_2} = \left(\frac{R_1}{R_2}\right)^3$

Given, $R_1 = R,\ R_2 = \frac{R}{2},\ A_1 = 56$

$$\therefore \quad \frac{56}{A_2} = \left(\frac{R}{R/2}\right)^3 = 2^3 = 8$$

or $A_2 = \frac{56}{8} = 7$

Thus, required stable nucleus will be Li^7.

47 The activity of a radioactive sample is measured as 9750 counts/min at $t = 0$ and as 975 counts/min at $t = 5$ min. The decay constant is approximately **[CBSE AIPMT 1997]**

(a) 0.922/min (b) 0.691/min

(c) 0.461/min (d) 0.230/min

Ans. *(c)*

According to law of radioactivity

$$\frac{N}{N_0} = e^{-\lambda t} \quad \text{...(i)}$$

$$\Rightarrow \quad \frac{N_0}{N} = e^{\lambda t}$$

$$\begin{bmatrix} N = \text{final concentration} \\ N_0 = \text{initial concentration} \\ \lambda = \text{decay constant} \end{bmatrix}$$

Taking logarithm on both sides of Eq. (i), we have

$$\log_e\left(\frac{N_0}{N}\right) = \log_e\left(e^{\lambda t}\right)$$

$$= \lambda t \log_e e = \lambda t$$

As we know that, $\log_e x = 2.3026 \log_{10} x$

Making substitution, we get

$$\lambda = \frac{2.3026 \log_{10}\left(\frac{9750}{975}\right)}{5}$$

$[\because N_0 = 9750$ counts/min and $N = 975$ counts/min$]$

$$= \frac{2.3026}{5}\log_{10} 10 = \frac{2.3026}{5}\ \text{min}^{-1}$$

$$= 0.461\ \text{min}^{-1}$$

48 The most penetrating radiation out of the following is **[CBSE AIPMT 1997]**

(a) γ-rays (b) α-particles

(c) β-rays (d) X-rays

Ans. *(a)*

The penetrating power of radiation is directly proportional to the energy of its photon.

$$\text{Energy of photon} = \frac{hc}{\lambda} \propto \frac{1}{\lambda}(\text{wavelength})$$

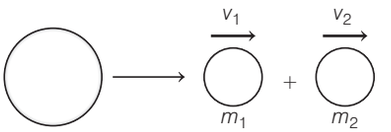
$$\therefore \text{ Penetrating power} \propto \frac{1}{\lambda}(\text{wavelength})$$

Since, λ is minimum for γ-rays, so penetrating power is maximum for γ-rays.

49 A nucleus ruptures into two nuclear parts, which have their velocity ratio equal to 2 : 1. What will be the ratio of their nuclear size (nuclear radius)? **[CBSE AIPMT 1996]**

(a) $2^{1/3} : 1$ (b) $1 : 2^{1/3}$ (c) $3^{1/2} : 1$ (d) $1 : 3^{1/2}$

Ans. *(b)*



From law of conservation of momentum

$$0 = m_1v_1 + m_2v_2$$

$$\therefore \quad m_1v_1 = -m_2v_2$$

or $\frac{v_1}{v_2} = -\frac{m_2}{m_1} = \frac{2}{1}$

One sign indicates that velocity is in opposite direction

As nucleus is assumed to be spherical of radius r, density ρ.

$$\therefore \quad m = \frac{4}{3}\pi r^3\rho \ \Rightarrow\ m \propto r^3$$

So for two different parts of nuclei,

$$\frac{m_2}{m_1} = \frac{r_2^3}{r_1^3}$$

$$\therefore \quad \frac{v_1}{v_2} = \frac{r_2^3}{r_1^3} \quad \text{or} \quad \frac{r_1}{r_2} = \left(\frac{v_2}{v_1}\right)^{1/3} = \left(\frac{1}{2}\right)^{1/3}$$

$$\Rightarrow \quad r_1 : r_2 = 1 : 2^{1/3}$$

50 The count rate of a Geiger Muller counter for the radiation of a radioactive material of half-life 30 min decreases to 5 s^{-1} after 2 h. The initial count rate was **[CBSE AIPMT 1995]**

(a) 20 s^{-1} (b) 25 s^{-1} (c) 80 s^{-1} (d) 625 s^{-1}

Ans. *(c)*

The equation for initial and final count rate is

$$N = N_0\left(\frac{1}{2}\right)^n$$

$$\begin{bmatrix} N = \text{final count rate} \\ N_0 = \text{initial rate of radio-active atom} \end{bmatrix}$$

where, $n = \frac{t}{T_{1/2}}$

Here, $n = \frac{120}{30} = 4$

$[\because t = 2h = 2 \times 60\ \text{min} = 120\ \text{min}]$

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$\therefore \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

or $\quad N_0 = 16 \times N = 16 \times 5 = 80 \ s^{-1}$

51 What is the respective number of α and β-particles emitted in the following radioactive decay

$^{200}X_{90} \longrightarrow {}^{168}Y_{80}$?

[CBSE AIPMT 1995]

(a) 6 and 8 (b) 6 and 6
(c) 8 and 8 (d) 8 and 6

Ans. *(d)*

Suppose x α-particles and y β-particles are emitted

So, change in mass no. is given by

$4x = 200 - 168 = 32$

$x = 8$

and change in atomic no. is given by

$2x - y = 90 - 80 = 10$

putting value of x

or $\quad 2 \times 8 - y = 10$

So, no. of β-particles $\quad y = 6$

No. of α-particles $\quad x = 8$

Alternative

$^{200}X_{90} \longrightarrow {}^{168}Y_{80}$

As,

$^{200}X_{90} \longrightarrow (n_2He^4) + m(_{-1}\beta^0) + {}^{168}Y_{80}$

Therefore, in this reaction

$200 = 4n + 168$ or $n = \frac{200 - 168}{4} = 8$

Also, $\quad 90 = 2n - m + 80$

or $\quad m = 2n + 80 - 90$

$= 2 \times 8 + 80 - 90 = 6$

Thus, respective number of α and β-particles will be 8 and 6.

52 The mass number of He is 4 and that for sulphur is 32. The radius of sulphur nuclei is larger than that of helium by **[CBSE AIPMT 1994]**

(a) $\sqrt{8}$ (b) 4 (c) 2 (d) 8

Ans. *(c)*

Volume of a nucleus is proportional to its mass number A. If R is the radius of the nucleus assumed to be spherical, then its volume $(v) \propto A$ (mass No.)

So, $\left(\frac{4}{3}\pi R^3\right) \propto A$ or $R \propto A^{1/3}$

$\therefore \quad \frac{R_S}{R_{He}} = \left(\frac{A_S}{A_{He}}\right)^{1/3} = \left(\frac{32}{4}\right)^{1/3} = 2$

or $\quad R_S = 2R_{He}$

53 In a given reaction,

$_ZX^A \rightarrow {}_{Z+1}Y^A \rightarrow {}_{Z-1}K^{A-4} \rightarrow {}_{Z-1}K^{A-4}$

Radioactive radiations are emitted in the sequence of **[CBSE AIPMT 1993]**

(a) α, β, γ (b) γ, α, β (c) β, α, γ (d) γ, β, α

Ans. *(c)*

When a nucleus emits an alpha particle, its mass number decreases by 4 and charge/atomic no. decreases by 2. In β-particle emission, mass remains same but atomic number is increased by one. In γ-decay, daughter nucleus has the same charge number and same mass number as those of parent nucleus. Hence, sequence is

$_ZX^A \xrightarrow{\beta} {}_{Z+1}Y^A \xrightarrow{\alpha} {}_{Z-1}K^{A-4} \xrightarrow{\gamma} {}_{Z-1}K^{A-4}$

54 The mass density of a nucleus varies with mass number A as **[CBSE AIPMT 1992]**

(a) A^2 (b) A
(c) constant (d) $\frac{1}{A}$

Ans. *(c)*

Density of nuclear matter is the ratio of mass of nucleus and its volume.

If m is average mass of a nucleon and R is the nuclear radius, then mass of nucleus $= mA$, where A is the mass number of the element.

Volume of nucleus $= \frac{4}{3}\pi R^3$

$= \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$

As density of nuclear matter

$= \frac{\text{mass of nucleus}}{\text{volume of nucleus}}$

$\rho = \frac{mA}{\frac{4}{3}\pi R_0{}^3 A}$

$\therefore \quad \rho = \frac{3m}{4\pi R_0{}^3}$

As m and R_0 are constants, therefore density ρ of nuclear matter is constant.

55 If the nuclear force between two protons, two neutrons and between proton and neutron is denoted by F_{pp}, F_{nn} and F_{pn} respectively, then **[CBSE AIPMT 1991]**

(a) $F_{pp} \approx F_{nn} \approx F_{pn}$

(b) $F_{pp} \neq F_{nn}$ and $F_{pp} = F_{nn}$

(c) $F_{pp} = F_{nn} = F_{pn}$

(d) $F_{pp} \neq F_{nn} \neq F_{pn}$

Ans. *(c)*

Nuclear forces act between a pair of neutrons, a pair of protons and also between a neutron-proton pair, with the same strength. This shows that nuclear forces are independent of charge.

56 In the nucleus of $_{11}Na^{23}$, the number of protons, neutrons and electrons are **[CBSE AIPMT 1991]**

(a) 11, 12, 0 (b) 23, 12, 11
(c) 12, 11, 0 (d) 23, 11, 12

Ans. *(a)*

A nucleus of mass number A and atomic number Z contains Z protons and $(A - Z)$ neutrons. As an atom is electrically neutral, therefore number of peripheral electrons must be equal to Z, the number of protons inside the nucleus. In $_{11}Na^{23}$, $Z = 11$ i.e. number of protons = 11,

Mass number $A = 23$

Number of neutrons $= A - Z = 23 - 11 = 12$

There is no electron in the nucleus.

So, number of protons, neutrons and electrons are 11, 12, 0.

57 The half-life of radium is 1600 yr. The fraction of a sample of radium that would remain after 6400 yr **[CBSE AIPMT 1991]**

(a) $\frac{1}{4}$ (b) $\frac{1}{2}$ (c) $\frac{1}{8}$ (d) $\frac{1}{16}$

Ans. *(d)*

Number of atoms left after n half-lives is given by

$N = N_0\left(\frac{1}{2}\right)^n$

$\left[\begin{matrix} N_0 = \text{initial count} \\ N = \text{final count rate of the n half life} \end{matrix}\right]$

or $\quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^n$

where $\quad n = \frac{t}{T_{1/2}}$

$\therefore \quad n = \frac{6400}{1600} = 4 \quad \left[\begin{matrix} t = 6400 \\ T_{1/2} = 1600 \end{matrix}\right]$

$\therefore \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^4 = \frac{1}{16}$

58 The constituents of atomic nuclei are believed to be **[CBSE AIPMT 1991]**

(a) neutrons and protons
(b) protons only
(c) electrons and protons
(d) electrons, protons and neutrons

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Ans. *(a)*

According to proton-neutron hypothesis, a nucleus of mass number A and atomic number Z contains Z protons and $(A - Z)$ neutrons. Constituents of atomic nucleus are Nucleons i.e. neutron and proton.

59 The nucleus $_6C^{12}$ absorbs an energetic neutron and emits a beta particle (β). The resulting nucleus is **[CBSE AIPMT 1990]**

(a) $_7N^{14}$ (b) $_7N^{13}$ (c) $_5B^{13}$ (d) $_6C^{13}$

Ans. *(b)*

A nuclear reaction represents the transformation of one stable nucleus into another nucleus by bombarding the former with suitable high energy particles.

$$_6C^{12} + {}_0n^1 \rightarrow {}_6C^{13} \rightarrow {}_7N^{13} + {}_{-1}\beta^0 + Q$$ (Energy)

Resulting nucleus is of nitrogen having mass no. 13 and atomic no. 7

60 The ratio of the radii of the nuclei $_{13}Al^{27}$ and $_{52}Te^{125}$ is approximately **[CBSE AIPMT 1990]**

(a) 6 : 10 (b) 13 : 52
(c) 40 : 177 (d) 14 : 73

Ans. *(a)*

Experimental measurements show that volume of a nucleus is proportional to its mass number A. If R is the radius of the nucleus assumed to be spherical, then its volume and mass no. relation is given by

Volume $(V) \propto$ mass no. (A)

or $$\left(\frac{4}{3}\pi R^3\right) \propto A$$

or $$R \propto A^{1/3}$$

$$\therefore \quad \frac{R_{Al}}{R_{Te}} = \frac{(27)^{1/3}}{(125)^{1/3}} = \frac{3}{5} = \frac{6}{10}$$

61 Which of the following statements is true for nuclear forces ? **[CBSE AIPMT 1990]**

(a) They obey the inverse square law of distance.
(b) They obey the inverse third power law of distance
(c) They are short range forces
(d) They are equal in strength to electromagnetic forces

Ans. *(c)*

Nuclear forces are the short range forces of attraction which hold together the nucleons (neutrons and protons) in the tiny nucleus of an atom, inspite of strong electrostatic forces of repulsion between protons. Nuclear forces are charge independent forces. They are the strongest forces in nature. The magnitude of nuclear forces is 100 times that of electrostatic forces and 10^{38} times that of gravitational forces between nucleons. They are operative upto distances of the order of a few fermi. They are non-central forces.

62 The nuclei $_6C^{13}$ and $_7N^{14}$ can be described as **[CBSE AIPMT 1990]**

(a) isotones
(b) isobars
(c) isotopes of carbon
(d) isotopes of nitrogen

Ans. *(a)*

Isotones are the nuclides which contain the same number of neutrons. In $_6C^{13}$ and $_7N^{14}$, number of neutrons in carbon $= 13 - 6 = 7$ and number of neutrons in nitrogen $= 14 - 7 = 7$.

No. of neutrons is given by mass no. (A) – atomic no. (Z)

63 An element A decays into element C by a two step process

$$A \rightarrow B + {}_2He^4$$
$$B \rightarrow C + 2e^-$$

then **[CBSE AIPMT 1989]**

(a) A and C are isotopes
(b) A and C are isobars
(c) A and B are isotopes
(d) A and B are isobars

Ans. *(a)*

From equation (Ist) there is 1 ∝-decay in which B has atomic no. 2 less than A. In IInd case there is 2-β-decay in which C has atomic no. 2 greater than B, Since A and C have same atomic no. so they are called isotopes.

64 A radioactive element has half-life period 800 yr. After 6400 yr, what amount will remain ? **[CBSE AIPMT 1989]**

(a) $\frac{1}{2}$ (b) $\frac{1}{16}$
(c) $\frac{1}{8}$ (d) $\frac{1}{256}$

Ans. *(d)*

Number of atoms left after n half-lives is given by

$$N = N_0\left(\frac{1}{2}\right)^n \quad \text{or} \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^n$$

Number of half-lives,

$$n = \frac{t}{T} = \frac{6400}{800} = 8$$

$$\therefore \quad \frac{N}{N_0} = \left(\frac{1}{2}\right)^8 = \frac{1}{256}$$

Alternative

Let the initial part be unity

So, after 800 years, it will remain $= \frac{1}{2}$

after 1600 years, it will remain $= \frac{1}{4}$

after 2400 years, it will remain $= \frac{1}{8}$

after 3200 years, it will remain $= \frac{1}{16}$

after 4000 years, it will remain $= \frac{1}{32}$

after 4800 years, it will remain $= \frac{1}{64}$

after 5600 years, it will remain $= \frac{1}{128}$

after 6400 years, it will remain $= \frac{1}{256}$

65 The nucleus $_{48}Cd^{115}$, after two successive β-decay will give **[CBSE AIPMT 1988]**

(a) $_{46}Pa^{115}$ (b) $_{49}In^{114}$
(c) $_{50}Sn^{113}$ (d) $_{50}Sn^{115}$

Ans.*(d)*

When a parent nucleus emits a β-particle (i.e, an electron) mass number remains same because mass of electron is negligibly low. Atomic number is increased by one. The nucleus $_{48}Cd^{115}$ after two successive β-decays will give $_{50}Sn^{115}$.

66 A radioactive sample with a half-life of 1 month has the label : 'Activity = 2 microcurie on 1-8-1991'. What would be its activity two months earlier ? **[CBSE AIPMT 1988]**

(a) 1.0 microcurie (b) 0.5 microcurie
(c) 4 microcurie (d) 8 microcurie

Ans. *(d)*

The activity of a radioactive substance is defined as the rate at which the nuclei of its atoms in the sample disintegrate. In two half-lives, the activity becomes one-fourth. Two months is 2 half-life period. The activity, two months earlier was $2 \times 2^2 = 8$ microcurie.

Note

The activity of a radioactive sample is called one curie, if it undergoes 3.7×10^{10} disintegrations per second.

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TOPIC 2
Nuclear Fission & Fusion and Binding Energy

67 A nucleus with mass number 240 breaks into two fragments each of mass number 120, the binding energy per nucleon of unfragmented nuclei is 7.6 MeV while that of fragments is 8.5 MeV. The total gain in the binding energy in the process is **[NEET 2021]**

(a) 0.9 MeV (b) 9.4 MeV
(c) 804 MeV (d) 216 MeV

Ans. *(d)*

A nucleus with mass number 240 breaks into two fragment each of mass number 120.

$$X^{240} \longrightarrow Y^{120} + Z^{120}$$

Given, the binding energy per nucleon of unfragmented nuclei, $X = 7.6$ MeV

The binding energy per nucleon of fragmented nuclei, $Y = Z = 8.5$ MeV

Now, we shall determine the total gain in binding energy.

Gain in binding energy = Binding energy of products – Binding energy of reactants

Gain in binding energy

$= 2 \times 120 \times 8.5 - 240 \times 7.6$

$= 216$ MeV

68 The energy equivalent of 0.5 g of a substance is **[NEET (Sep.) 2020]**

(a) 4.5×10^{13} J (b) 1.5×10^{13} J
(c) 0.5×10^{13} J (d) 4.5×10^{16} J

Ans. *(a)*

Given, $m = 0.5\,\text{g} = 0.5 \times 10^{-3}$ kg

Relation for energy equivalent of mass is

$$E = mc^2$$

where, c is speed of light.

$$= 0.5 \times 10^{-3} \times (3 \times 10^8)^2 \quad (\because c = 3 \times 10^8)$$

$$= 4.5 \times 10^{13}\ \text{J}$$

Hence, correct option is (a).

69 When a uranium isotope $^{235}_{92}\text{U}$ is bombarded with a neutron, it generates $^{89}_{36}\text{Kr}$, three neutrons and **[NEET (Sep.) 2020]**

(a) $^{91}_{40}\text{Zr}$ (b) $^{101}_{36}\text{Kr}$ (c) $^{103}_{36}\text{Kr}$ (d) $^{144}_{56}\text{Ba}$

Ans. *(d)*

Here,

$$^{235}_{92}\text{U} + {}^{1}_{0}n \longrightarrow {}^{89}_{36}\text{Kr} + {}^{A}_{Z}X + 3({}^{1}_{0}n)$$

According to the law of conservation,

$$(\text{Atomic number})_{\text{Reactant}} = (\text{Atomic number})_{\text{Product}}$$

$$92 + 0 = 36 + Z$$

$$\Rightarrow \quad Z = 92 - 36 = 56$$

Similarly,

$$(\text{Atomic masses})_{\text{Reactant}} = (\text{Atomic masses})_{\text{Product}}$$

$$235 + 1 = 89 + A + 3 \times 1$$

$$\Rightarrow \quad A = 144$$

$\therefore$ Other element is $^{144}_{56}\text{Ba}$.

Hence, correct option is (d).

70 A nucleus of uranium decays at rest into nuclei of thorium and helium. Then, **[CBSE AIPMT 2015]**

(a) the helium nucleus has more kinetic energy than the thorium nucleus
(b) the helium nucleus has less momentum than the thorium nucleus
(c) the helium nucleus has more momentum than the thorium nucleus
(d) the helium nucleus has less kinetic energy than the thorium nucleus

Ans. *(a)*

$$_{92}\text{U}^{238} \longrightarrow {}_{92}\text{Th}^{238} + {}_{2}\text{He}^{4}$$

According to law of conservation of linear momentum, we have.

$$|P_{\text{Th}}| = |P_{\text{He}}| = P$$

$\Rightarrow$ As, kinetic energy of an element,

$$\text{KE} = \frac{P^2}{2m}$$

where, m is mass of an element.

Thus, $\quad \text{KE} \propto \frac{1}{M}$

So, $\quad M_{\text{He}} < M_{\text{Th}} \Rightarrow K_{\text{He}} > K_{\text{Th}}$

71 The binding energy per nucleon of $^{7}_{3}\text{Li}$ and $^{4}_{2}\text{He}$ nuclei are 5.60 MeV and 7.06 MeV, respectively. In the nuclear reaction $^{7}_{3}\text{Li} + {}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{4}_{2}\text{He} + Q$, the value of energy Q released is **[CBSE AIPMT 2014]**

(a) 19.6 MeV (b) – 2.4 MeV
(c) 8.4 MeV (d) 17.3 MeV

Ans. *(d)*

The binding energy for $_{1}\text{H}^{1}$ is around zero and also not given in the question so we can ignore it

$$Q = 2(4 \times 7.06) - (7 \times 5.60)$$

$$= 2(E_{bn} \text{ of He}) - (E_{bn} \text{ of Li})$$

$$= (8 \times 7.06) - (7 \times 5.60)$$

$$= (56.48 - 39.2)\ \text{MeV}$$

$\therefore \quad Q = 17.28\,\text{MeV} \simeq 17.3\,\text{MeV}$

72 A certain mass of hydrogen is changed to helium by the process of fusion. The mass defect in fusion reaction is 0.02866 u. The energy liberated per u is (given $1\,\text{u} = 931$ MeV) **[NEET 2013]**

(a) 2.67 MeV (b) 26.7 MeV
(c) 6.675 MeV (d) 13.35 MeV

Ans. *(c)*

Given, $\Delta m = 0.02866$ u

$\therefore$ Energy liberated $= \Delta mc^2$

$\Rightarrow$ Energy liberated per u

$$= \frac{0.02866 \times 931}{4} = \frac{26.7}{4}\ \text{MeV}$$

$$= \frac{E_b}{A} = 6.675\,\text{MeV}$$

73 Fusion reaction takes place at high temperature because **[CBSE AIPMT 2011]**

(a) atoms get ionised at high temperature
(b) kinetic energy is high enough to overcome the coulomb repulsion between nuclei
(c) molecules break up at high temperature
(d) nuclei break up at high temperature

Ans. *(b)*

Fusion reaction takes place at high temperature because kinetic energy is high enough to overcome the couloumb repulsion between nuclei.

74 The mass of a $^{7}_{3}\text{Li}$ nucleus is 0.042u less than the sum of the masses of all its nucleons. The binding energy per nucleon of $^{7}_{3}\text{Li}$ nucleus is nearly **[CBSE AIPMT 2010]**

(a) 46 MeV (b) 5.6 MeV
(c) 3.9 MeV (d) 23 MeV

Ans. *(b)*

If $m = 1$ u, $c = 3 \times 10^8\,\text{ms}^{-1}$, then

$E = 931$ MeV i.e. $1\,\text{u} = 931$ MeV

Binding energy $= 0.042 \times 931 = 39.10$ MeV

$\therefore$ Binding energy per nucleon

$$= \frac{39.10}{7} = 5.58 \simeq 5.6\,\text{MeV}$$

75 A nucleus $^{A}_{Z}X$ has mass represented by $m(A, Z)$. If m_p and m_n denote the mass of proton and neutron respectively and BE the binding energy (in MeV), then **[CBSE AIPMT 2007]**

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(a) $BE = [m(A, Z) - Zm_p - (A - Z)\, m_n]\, c^2$
(b) $BE = [Zm_p + (A - Z)\, m_n - m(A, Z)]\, c^2$
(c) $BE = [Zm_p + Am_n - m(A, Z)]\, c^2$
(d) $BE = m(A, Z) - Zm_p - (A - Z)\, m_n$

Ans. ***(b)***

In the case of formation of a nucleus, the evolution of energy equal to the binding energy of the nucleus takes place due to disappearance of a fraction of the total mass. If the quantity of mass disappearing is Δm, then the binding energy is

$$BE = \Delta mc^2$$

From the above discussion, it is clear that the mass of the nucleus must be less than the sum of the masses of the consituent neutrons and protons. We can then write.

$$\Delta m = Zm_p + Nm_n - m(A, Z)$$

where $m(A, Z)$ is the mass of the atom of mass number A and atomic number Z. Hence, the binding energy of the nucleus is

$$BE = [Zm_p + Nm_n - m(A, Z)]c^2$$
$$BE = [Zm_p + (A - Z)\, m_n - m(A, Z)]c^2$$

where, $N = A - Z$ = number of neutrons.

76 The binding energy of deuteron is 2.2 MeV and that of $_2^4He$ is 28 MeV. If two deuterons are fused to form one $_2^4He$, then the energy released is **[CBSE AIPMT 2006]**

(a) 25.8 MeV (b) 23.6 MeV
(c) 19.2 MeV (d) 30.2 MeV

Ans. ***(b)***

The reaction can be written as

$$_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + \text{energy}$$

The energy released in the reaction is the difference of binding energies of daughter and parent nuclei.

Hence, energy released
= binding energy of $_2He^4$
$-2 \times$ binding energy of $_1H^2$
$= 28 - 2 \times 2.2 = 23.6$ MeV

77 In any fission process the ratio $\frac{\text{mass of fission products}}{\text{mass of parent nucleus}}$ is **[CBSE AIPMT 2005]**

(a) less than 1
(b) greater than 1
(c) equal to 1
(d) depends on the mass of parent nucleus

Ans. ***(a)***

In fission process, when a parent nucleus breaks into daughter products, then some mass is lost in the form of energy.

Thus,
mass of fission products < mass of parent nucleus

$$\Rightarrow \frac{\text{Mass of fission products}}{\text{Mass of parent nucleus}} < 1$$

78 Fission of nuclei is possible because the binding energy per nucleon in them **[CBSE AIPMT 2005]**

(a) increases with mass number at high mass numbers
(b) decreases with mass number at high mass numbers
(c) increases with mass number at low mass numbers
(d) decreases with mass number at low mass numbers

Ans. ***(b)***

The binding energy per nucleon for the middle nuclides (from $A = 20$ to $A = 56$) is maximum. Hence, these are more stable. As the mass number increases, the binding energy per nucleon gradually decreases and ultimately binding energy per nucleon of heavy nuclides (such as uranium etc.) is comparatively low. Hence, these nuclides are relatively unstable. So, they can be fissioned easily.

79 In the reaction $_1^2H + {}_1^3H \rightarrow {}_2^4He + {}_0^1n$, if the binding energies of $_1^2H$, $_1^3H$ and $_2^4He$ are respectively a, b and c (in MeV), then the energy (in MeV) released in this reaction is **[CBSE AIPMT 2005]**

(a) $c + a - b$ (b) $c - a - b$
(c) $a + b + c$ (d) $a + b - c$

Ans. ***(b)***

Given, Binding energy of $(_1^2H + {}_1^3H) = a + b$
Binding energy of $_2^4He = c$

In a nuclear reaction, the resultant nucleus is more stable than the reactants. Hence, binding energy of $_2^4He$ will be more than that of $(_1^2H + {}_1^3H)$.

Thus, energy released per nucleon
= resultant binding energy
Binding energy of product – Binding energy of reactants
$= c - (a + b) = c - a - b$

80 m_p denotes the mass of a proton and m_n that of a neutron. A given nucleus of binding energy BE, contains Z protons and N neutrons. The mass $m(N, Z)$ of the nucleus is given by **[CBSE AIPMT 2004]**

(a) $m(N, Z) = Nm_n + ZM_p - BEc^2$
(b) $m(N, Z) = Nm_n + Zm_p + BEc^2$
(c) $m(N, Z) = Nm_n + Zm_p - BE/c^2$
(d) $m(N, Z) = Nm_n + Zm_p + BE/c^2$

Ans. ***(c)***

Binding energy of a nucleus containing N neutrons and Z protons is

$$BE = [Nm_n + Zm_p - m(N, Z)]\, c^2$$
$$\Rightarrow \quad \frac{BE}{c^2} = Nm_n + Zm_p - m(N, Z)$$
$$\Rightarrow m(N, Z) = Nm_n + Zm_p - BE/c^2$$

81 If in a nuclear fusion process, the masses of the fusing nuclei be m_1 and m_2 and the mass of the resultant nucleus be m_3, then **[CBSE AIPMT 2004]**

(a) $m_3 = m_1 + m_2$
(b) $m_3 = |m_1 - m_2|$
(c) $m_3 < (m_1 + m_2)$
(d) $m_3 > (m_1 + m_2)$

Ans. ***(c)***

In a nuclear fusion, when two light nuclei of different masses are combined to form a stable nucleus, then some mass is lost and appears in the form of energy, called the mass defect. So, the mass of resultant nucleus is always less than the sum of masses of initial nuclei i.e.,

$$m_3 < (m_1 + m_2)$$

82 Solar energy is mainly caused due to **[CBSE AIPMT 2003]**

(a) fusion of protons during synthesis of heavier elements
(b) gravitational contraction
(c) burning of hydrogen in the oxygen
(d) fission of uranium present in the sun

Ans. ***(a)***

In sun, huge amount of energy is produced due to fusion of 4 protons (hydrogen nucleus) into a helium nucleus. According to the reaction

$$_1H^1 + {}_1H^1 + {}_1H^1 + {}_1H^1 \longrightarrow {}_2He^4 + 2\,{}_{+1}\beta^0 + \gamma\,(\text{energy}) + 2\upsilon$$

83 The mass of proton is 1.0073 u and that of neutron is 1.0087 u (u = atomic mass unit) The binding energy of $_2He^4$ is (mass of helium nucleus = 4.0015 u) **[CBSE AIPMT 2003]**

(a) 28.4 MeV (b) 0.061 u
(c) 0.0305 J (d) 0.0305 erg

Ans. ***(a)***

$_2He^4$ contains 2 neutrons and 2 protons
So, mass of 2 protons
$= 2 \times 1.0073 = 2.0146$ u
So, mass of 2 neutrons

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$= 2 \times 1.0087 = 2.0174$ u

Total mass of 2 protons and 2 neutrons
$= (2.0146 + 2.0174)$ u $= 4.032$ u

Mass of helium nucleus = 4.0015 u

Thus, mass defect is lacking of mass in forming the helium nucleus from 2 protons and 2 neutrons.

$\therefore \Delta m$ = mass defect $= (4.032 - 4.0015)$ u
$= 0.0305$ u

As we know that, 1u = 931 MeV

Hence, binding energy
$\Delta E = (\Delta m) \times 931$
$= 0.0305 \times 931 = 28.4$ MeV

84 When a deuterium is bombarded on ${}_8O^{16}$ nucleus, an α-particle is emitted, then the product nucleus is **[CBSE AIPMT 2002]**

(a) ${}_7N^{13}$ (b) ${}_5B^{10}$ (c) ${}_4Be^{9}$ (d) ${}_7N^{14}$

Ans. *(d)*

Let the unknown product nucleus be ${}_ZX^A$.

The reaction can be written as

$${}_8O^{16} + {}_1H^2 \longrightarrow {}_ZX^A + {}_2He^4$$
(Oxygen) (deuterium) (unknown nucleus) (α – particle)

Conservation of mass number between product and reactant of above reaction gives,

$$16 + 2 = A + 4 \Rightarrow A = 14$$

Conservation of atomic number between reactant and product of above reaction gives

$$8 + 1 = Z + 2 \Rightarrow Z = 7$$

Thus, the unknown product nucleus is nitrogen (${}_7N^{14}$).

Note

Fusion reaction can take place at very high temperature ($\approx 10^8$ K) and very high pressure which can be provided at sun or by fission of atom bomb.

85 Which of the following are suitable for the fusion process ? **[CBSE AIPMT 2002]**

(a) Light nuclei
(b) Heavy nuclei
(c) Elements lying in the middle of periodic table
(d) Elements lying in the middle of binding energy curve

Ans. *(a)*

Binding energy for light nuclei ($A < 20$) is much smaller than the binding energy for heavier nuclei. This suggests a process that is reverse of fission. When two light nuclei combine to form a heavier nucleus, the process is called nuclear fusion. The union of two light nuclei into heavier nuclei also lead to a transfer of mass and a consequent liberation of large amount energy.

86 In nuclear fission process, energy is released because **[CBSE AIPMT 2001]**

(a) mass of products is more than mass of nucleus
(b) total binding energy of products formed due to nuclear fission is more than the parent fissionable material
(c) total binding energy of products formed due to nuclear fission is less than parent fissionable material
(d) mass of some particles is converted into energy

Ans. *(b)*

In a nuclear process, energy is released if binding energy per nucleon of the daughter products gets increased. In nuclear fission reaction, total binding energy of products formed due to nuclear fission is more than the parent fissionable material.

87 m_p and m_n are masses of proton and neutron respectively. An element of mass m has Z protons and N neutrons, then **[CBSE AIPMT 2001]**

(a) $m > Zm_p + Nm_n$
(b) $m = Zm_p + Nm_n$
(c) $m < Zm_p + Nm_n$
(d) m may be greater than, less than or equal to $Zm_p + Nm_n$, depending on nature of element

Ans. *(c)*

When a nucleus is formed, then the mass of nucleus is slightly less than the sum of masses of Z protons and N neutrons.

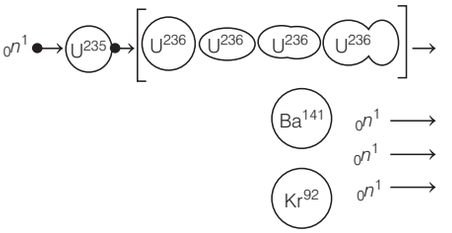
i.e., $m < (Zm_p + Nm_n)$

88 Nuclear fission can be explained by **[CBSE AIPMT 2000]**

(a) proton-proton cycle
(b) liquid drop model of nucleus
(c) independent of nuclear particle model
(d) nuclear shell model

Ans. *(b)*

Neil Bohr and J.A. Wheeler explained the nuclear fission on the basis of liquid drop model of the nucleus. The ${}_{92}U^{235}$ nucleus behaves like a liquid drop and owing to surface tension is perfectly spherical in shape. When the neutron strikes the nucleus, some energy called the excitation energy is imparted to the nucleus.



The phenomenon of surface tension tries to keep the nucleus spherical in shape, whereas the excitation energy tries to deform it. Due to the struggle between the surface tension and the excitation energy, the oscillations are set up inside the compound nucleus.

As a result, the nucleus gets deformed from spherical shape to ellipsoidal and then to a dumb bell as shown, till the Coulomb's repulsive force between protons succeeds in tearing the two bells apart.

89 Complete the equation for the following fission process

$${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{38}Sr^{90} + ...$$
[CBSE AIPMT 1998]

(a) ${}_{54}Xe^{143} + 3\,{}_0n^1$
(b) ${}_{54}Xe^{145}$
(c) ${}_{57}Xe^{142}$
(d) ${}_{54}Xe^{142} + {}_0n^1$

Ans. *(a)*

${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{38}Sr^{90} + {}_{54}Xe^{143} + 3\,{}_0n^1$

If total atomic number on LHS
$= 92 + 0 = 92$

Total atomic number on RHS
$= 38 + 54 + 0 = 92$

Total mass number on LHS
$= 235 + 1 = 236$

Total mass number on RHS
$= 90 + 143 + 3 \times 1 = 236$

So, option (a) is correct.

Note

For a nuclear reaction to be completed, the mass number and charge number on both sides should be same.

90 In a fission reaction,

$${}^{236}_{92}U \rightarrow {}^{117}X + {}^{117}Y + n + n$$

the binding energy per nucleon of X and Y is 8.5 MeV whereas of ${}^{236}U$ is 7.6 MeV. The total energy liberated will be about **[CBSE AIPMT 1997]**

(a) 2000 MeV (b) 200 MeV
(c) 2 MeV (d) 1 keV

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Ans. *(b)*

Binding energy of fissioned nucleus
$= 236 \times 7.6$ MeV

Binding energy of products
$= 117 \times 8.5 + 117 \times 8.5$
$= 2 \times 117 \times 8.5$

Hence, net binding energy = binding energy of products – binding energy of fissioned nucleus
$= 234 \times 8.5 - 236 \times 7.6$
$= 1989 - 1793.6 = 195.4$ MeV
≈ 200 MeV

Thus, in per fission of uranium nearly 200 MeV energy is released.

91 Which of the following is used as a moderator in nuclear reactors ? **[CBSE AIPMT 1997]**

(a) Plutonium (b) Cadmium
(c) Heavy water (d) Uranium

Ans. *(c)*

Moderator in a nuclear reactor is used to slow down the fast moving neutrons. Heavy water, graphite or beryllium oxide are used as moderators. Heavy water is best moderator.

Note

In an ordinary uranium reactor, plutonium (Pu^{239}) is produced which is a better fissionable material than uranium (U^{235}) . It is a heavy isotope of uranium.

92 Heavy water is used as a moderator in a nuclear reactor. The function of the moderator is **[CBSE AIPMT 1994]**

(a) to control energy released in the reactor
(b) to absorb neutrons and stop chain reaction
(c) to cool the reactor
(d) to slow down the neutrons to thermal energies

Ans. *(d)*

The function of a moderator is to slow down the fast moving secondary neutrons produced during the fission as fission reaction can only be initiated by slow moving neutrons.

The material of moderator should be light and it should not absorb neutrons. Usually, heavy water, graphite, deuterium, paraffin etc. can act as moderators. These moderators are rich in protons.

93 If the binding energy per nucleon in ${}_3Li^7$ and ${}_2He^4$ nuclei are respectively 5.60 MeV and 7·06 MeV, then the energy of proton in the reaction ${}_3Li^7 + p \longrightarrow 2\,{}_2He^4$ is **[CBSE AIPMT 1994]**

(a) 19.6 MeV
(b) 2.4 MeV
(c) 8.4 MeV
(d) 17.3 MeV

Ans. *(d)*

Total BE of nucleons in ${}_3Li^7$
$= 7 \times 5.60 = 39.20$ MeV

Total BE of nucleons in $2({}_2He^4)$
$= (4 \times 7.06) \times 2 = 56.48$ MeV

Therefore, energy of protons in the reaction
= difference of BE's
$= 56.48 - 39.20 = 17.3$ MeV

94 Energy released in the fission of a single ${}_{92}U^{235}$ nucleus is 200 MeV. The fission rate of a ${}_{92}U^{235}$ filled reactor operating at a power level of 5 W is **[CBSE AIPMT 1993]**

(a) $1.56 \times 10^{-10}\ s^{-1}$ (b) $1.56 \times 10^{11}\ s^{-1}$
(c) $1.56 \times 10^{-16}\ s^{-1}$ (d) $1.56 \times 10^{-17}\ s^{-1}$

Ans. *(b)*

$$\text{Fission rate} = \frac{\text{total nuclear power}}{\text{energy produced / fission}}$$

Here, total nuclear power = 5 W
Energy released per fission = 200 MeV

$$\therefore \text{Fission rate} = \frac{5}{200\ \text{MeV}}$$

$$= \frac{5}{200 \times 1.6 \times 10^{-13}} \quad [\because 1\ \text{MeV} = 1.6 \times 10^{-13}\ \text{J}]$$

$$= 1.56 \times 10^{11}\ s^{-1}$$

95 The binding energy per nucleon is maximum in case of **[CBSE AIPMT 1993]**

(a) ${}_2He^4$ (b) ${}_{26}Fe^{56}$
(c) ${}_{56}Ba^{141}$ (d) ${}_{92}U^{235}$

Ans. *(b)*

The binding energy curve has a broad maximum in the range $A = 30$ to $A = 120$ corresponding to average binding energy per nucleon = 8 MeV. The peak value of the maximum is 8.8 MeV/N for ${}_{26}Fe^{56}$.

96 The energy equivalent of one atomic mass unit is **[CBSE AIPMT 1992]**

(a) 1.6×10^{-19} J (b) 6.02×10^{23} J
(c) 931 MeV (d) 9.31 MeV

Ans. *(c)*

According to Einstein, mass-energy equivalence is represented by $E = mc^2$.

Taking, mass, $m = 1$ amu
$= 1.66 \times 10^{-27}$ kg,
and velocity of light in vacuum,
$c = 3.0 \times 10^8$ m/s

We get, $E = (1.66 \times 10^{-27}) \times (3 \times 10^8)^2$ J
$= 1.49 \times 10^{-10}$ J $= \dfrac{1.49 \times 10^{-10}}{1.6 \times 10^{-13}}$ MeV
$(\because 1\ \text{MeV} = 1.6 \times 10^{-13}\ \text{J})$
$= 931.25$ MeV

Hence, 1 amu ≈ 931 MeV

97 Solar energy is due to **[CBSE AIPMT 1992]**

(a) fusion reaction
(b) fission reaction
(c) combustion reaction
(d) chemical reaction

Ans. *(a)*

Stellar energy is the energy obtained continuously from the sun and the stars. It is estimated that the sun has been radiating 3.8×10^{26} J of energy per second for billions of years. Bethe postulated that the interior of the sun and stars provide conditions for the fusion of hydrogen nuclei to form helium nuclei with the release of heavy amount of energy. Hence, solar energy is due to fusion reaction.

98. The average binding energy of a nucleon inside an atomic nucleus is about **[CBSE AIPMT 1989]**

(a) 8 MeV (b) 8 eV
(c) 8 J (d) 8 erg

Ans. *(a)*

Average binding energy per nucleon of a nucleus is the average energy we have to spend to remove a nucleon from the nucleus to infinite distance. It is given by total binding energy divided by the mass number of the nucleus. The BE curve has a broad maximum in the range $A = 30$ to $A = 120$ corresponding to average binding energy per nucleon = 8 MeV. The peak value of the maximum is 8 MeV/N for ${}_{26}Fe^{56}$.

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28

Semiconductor Electronics

TOPIC 1
Semiconductor and *p-n* Junction Diode

01 The electron concentration in an *n*-type semiconductor is the same as hole concentration in a *p*-type semiconductor. An external field (electric) is applied across each of them. Compare the currents in them. **[NEET 2021]**

(a) Current in *n*-type = Current in *p*-type
(b) Current in *p*-type > Current in *n*-type
(c) Current in *n*-type> Current in *p*-type
(d) No current will flow in *p*-type. current will only flow in *n*-type

Ans. *(c)*

Given, the electron concentration in *n*-type semiconductor is equal to the hole's concentration in *p*-type semiconductor.

When electric field is applied across the semiconductor, the electrons and holes will move opposite to each other. The mobility of *n*-type semiconductor is greater than mobility of *p*-type semiconductor.

So, the current in the *n*-type semiconductor is greater than current in the *p*-type semiconductor.

02 Consider the following statements (A) and (B) and identify the correct answer.

(A) A Zener diode is connected in reverse bias, when used as a voltage regulator. **[NEET 2021]**

(B) The potential barrier of *p-n* junction lies between 0.1 V to 0.3 V.

(a) (A) and (B) both are correct.
(b) (A) and (B) both are incorrect.
(c) (A) is correct and (B) is incorrect.
(d) (A) is incorrect but (B) is correct.

Ans. *(c)*

Zener diode is a type of special *p-n* junction diode that operates in reverse bias. Thus, it is used as a voltage regulator. So, the statement (A) is correct. The potential barrier of *p-n* junction for silicon is 0.6-0.7 V and for germanium is 0.2-0.35 V. So, the statement (B) is incorrect.

03 Out of the following which one is a forward biased diode? **[NEET (Oct.) 2020]**

(a)

(b)

(c)

(d)

Ans. *(d)*

A *p-n* junction diode is in forward biased when *p*-side is connected with more positive potential than *n*-side.

Since, $0\,V > -3\,V$.

Hence in option (d), diode circuit is in forward biased.

04 An intrinsic semiconductor is converted into *n*-type extrinsic semiconductor by doping it with **[NEET (Oct.) 2020]**

(a) phosphorous (b) aluminium
(c) silver (d) germanium

Ans. *(a)*

When a pentavalent (phosphorous) impurities is doped with intrinsic semiconductor (Ge, Si), then *n*-type semiconductor is formed.

05 The increase in the width of the depletion region in a *p-n* junction diode is due to **[NEET (Sep.) 2020]**

(a) reverse bias only
(b) both forward bias and reverse bias
(c) increase in forward current
(d) forward bias only

Ans. *(a)*

Under reverse bias condition, the holes of *p*-side are attracted towards the negaive terminal of the battery and electrons of the *n*-side are attracted towards the positive terminal of the battery. This increases the width of the depletion layer.

However, in the case of forward biasing, the width of the depletion layer decreases.

Hence, correct option is (a).

06 The solids which have the negative temperature coefficient of resistance are **[NEET (Sep.) 2020]**

(a) insulator only
(b) semiconductors only
(c) insulators and semiconductors
(d) metals

Ans. *(c)*

Insulators and semiconductors are those solids, which have negative temperature coefficient of resistance. As, when temperature increases number of free electrons increases in both insulator and semiconductor.

Hence, correct option is (c).

07 An LED is constructed from a p-n junction diode using GaAsP. The energy gap is 1.9 eV. The wavelength of the light emitted will be equal to **[NEET (Odisha) 2019]**

(a) 10.4×10^{-26} m (b) 654 nm
(c) 654 Å (d) 654×10^{-11} m

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Ans. *(b)*

The energy of light of wavelength λ is given by

$$E = h\nu = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} \quad ...(i)$$

Here, h = Planck's constant

$= 6.63 \times 10^{-34}$ J-s

c = speed of light $= 3 \times 10^8$ m/s

E = energy gap $= 1.9$ eV $= 1.9 \times 1.6 \times 10^{-19}$ J

Substituting the given values in Eq. (i), we get

$$\Rightarrow \quad \lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.9 \times 1.6 \times 10^{-19}}$$

$$= 6.54 \times 10^{-7} \text{ m} \approx 654 \text{ nm}$$

Thus, the wavelength of light emitted from LED will be 654 nm.

08 For a *p*-type semiconductor, which of the following statements is true ?

[NEET (National) 2019]

(a) Holes are the majority carriers and trivalent atoms are the dopants.
(b) Holes are the majority carriers and pentavalent atoms are the dopants.
(c) Electrons are the majority carriers and pentavalent atoms are the dopants.
(d) Electrons are the majority carriers and trivalent atoms are the dopants.

Ans. *(a)*

p-type semiconductors are obtained when a trivalent impurity (e.g. boron, aluminium, gallium or indium) is added to a intrinsic semiconductor. (e.g. germanium or silicon).

In other words, the dopants in *p*-type semiconductor is trivalent atom.

Thus, this addition creates deficiencies of valence electron which are most commonly known as holes. These are the majority charge carriers in this type of semiconductor. However, in *n*-type semiconductors, the dopants are pentavalent impurities. Also, the majority charge carriers are electrons.

09 In a *p-n* junction diode, change in temperature due to heating

[NEET 2018]

(a) does not affect resistance of *p-n* junction
(b) affects only forward resistance
(c) affects only reverse resistance
(d) affects the overall *V-I* characteristics of *p-n* junction

Ans. *(d)*

Due to increase in temperature because of heating, thermal collision between the electron and holes increases. Thus, net electron-hole pairs increase.

This leads to increase in the current in diode and overall resistance of the diode changes.

This in turn changes both the forward biasing and the reverse biasing.

Thus, the overall *I-V* characteristics of *p-n* junction diode gets affected.

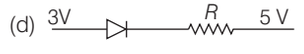
10 Which one of the following represents forward bias diode?

[NEET 2017]

(a)

(b)

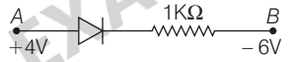
(c)

(d) 

Ans. *(a)*

In the forward biasing of *P-N* junction, *p* side of junction diode is connected to higher potential and *n* side of junction diode is connected to lower potential. Hence, the option (a) is correct answer.

11 Consider the junction diode as ideal. The value of current flowing through *AB* is **[NEET 2016]**



(a) 10^{-2} A (b) 10^{-1} A (c) 10^{-3} A (d) 0 A

Ans. *(a)*

Let us assume that current through the diode is *I*.

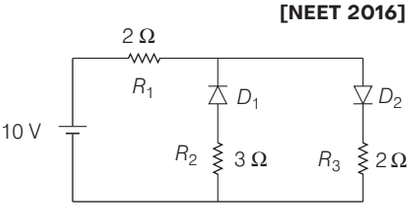
From the given condition

$$\because \quad I = \frac{V_A - V_B}{R} = \frac{4-(-6)}{1\text{K}\Omega}$$

$$= \frac{10}{1 \times 10^3} = 10^{-2} \text{ A}$$

12 The given circuit has two ideal diodes connected as shown in the figure below. The current flowing through the resistance R_1 will be

[NEET 2016]



(a) 2.5 A (b) 10.0 A
(c) 1.43 A (d) 3.13 A

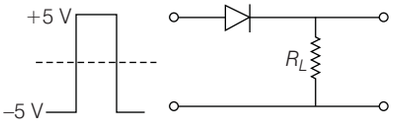
Ans. *(a)*

We know that a diode only conducts in forward biased condition. In the given circuit, the diode D_1 will be in reverse bias, so it will block the current and diode D_2 will be in forward bias, so it will pass the current

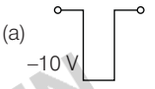
$$i = \frac{V}{R_1 + R_3} = \frac{10}{2+2} = 2.5 \text{ A}$$

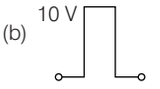
13 If in a *p-n* junction, a square input signal of 10 V is applied as shown,

[CBSE AIPMT 2015]

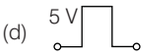


then the output across R_L will be

(a) 

(b) 

(c)

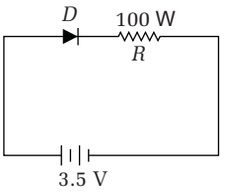
(d) 

Ans. *(d)*

As it is forward biased so it takes positive value. Hence, option (d) is correct.

14 In the given figure, a diode *D* is connected to an external resistance $R = 100\,\Omega$ and an e.m.f of **3.5** V. If the barrier potential developed across the diode is **0.5** V, the current in the circuit will be

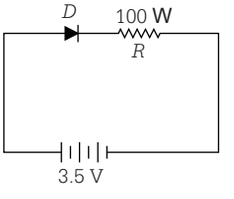
[CBSE AIPMT 2015]



(a) 30 mA (b) 40 mA
(c) 20 mA (d) 35 mA

Ans. *(a)*

Given, external resistance $R = 100\,\Omega$ and an emf is 3.5 V.



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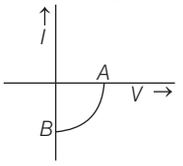
Potential barrier across the diode is 0.5 V,
Potential difference on
$R = 3.5\text{ V} - 0.5\text{ V} = 3.0\text{ V}$
Current in circuit,
$I = \frac{V}{R} = \frac{3}{100}$
$= 0.03\text{ A} = 30\text{ mA}$

15 The given graph represents *V-I* characteristic for a semiconductor device. Which of the following statement is correct?
[CBSE AIPMT 2014]



(a) It is *V-I* characteristic for solar cell where point *A* represents open circuit voltage and point *B* short circuit current
(b) It is for a solar cell and points *A* and *B* represent open circuit voltage and current, respectively
(c) It is for a photodiode and points *A* and *B* represent open circuit voltage and current, respectively
(d) It is for a LED and points *A* and *B* represent open circuit voltage and short circuit current respectively

Ans. *(a)*
V-I characteristics of a solar cell is shown. Where, A represents open circuit voltage
(i.e. $I = 0, V = \text{emf}$) and *B* shows short circuit voltage (i.e. $I = I, V = 0$).

16 The barrier potential of a *p-n* junction depends on
[CBSE AIPMT 2014]
(i) type of semiconductor material
(ii) amount of doping
(iii) temperature
Which one of the following is correct?
(a) (i) and (ii) only
(b) (ii) only
(c) (ii) and (iii) only
(d) (i), (ii) and (iii)

Ans. *(d)*
Barrier potential depends on all the three options given. Barrier potential depends on the material used to make *p-n* junction diode (whether it is Si or Ge). It also depends on amount of doping due to which the number of majority carriers will change. It also depends on temperature due to which the number of minority carriers will change.

17 In a *n*-type semiconductor, which of the following statement is true?
[NEET 2013]
(a) Electrons are majority carriers and trivalent atoms are dopants
(b) Electrons are minority carriers and pentavalent atoms are dopants
(c) Holes are minority carriers and pentavalent atoms are dopants
(d) Holes are majority carriers and trivalent atoms are dopants

Ans. *(c)*
The *n*-type semi-conductor can be produced by doping an impurity atom of valency 5
i.e. pentavalent atoms (phosphorus).
Holes are minority carriers in them.

18 C and Si both have same lattice structure, having 4 bonding electrons in each. However, C is insulator whereas Si is intrinsic semiconductor. This is because
[CBSE AIPMT 2012]
(a) in case of C, the valence bond is not completely filled at absolute zero temperature
(b) in case of C, the conduction band is partly filled even at absolute zero temperature
(c) the four bonding electrons in the case of C lie in the second orbit, whereas in the case of Si they lie in the third
(d) the four bonding electrons in the case of C lie in the third orbit, whereas for Si they lie in the fourth orbit

Ans. *(c)*
The four bonding electrons in the case of C lie in the second orbit, whereas in case of Si they lies in the third orbit. So loosely bounded valence electrons are present in Si as compared to C.

19 If a small amount of antimony is added to germanium crystal
[CBSE AIPMT 2011]
(a) the antimony becomes an acceptor atom
(b) there will be more free electrons than holes in the semiconductor
(c) its resistance is increased
(d) it becomes a *p*-type semiconductor

Ans. *(b)*
When a small amount of antimony is added to germanium crystal, the crystal becomes *n*-type semiconductor, because antimoney is a pentavalent substrate.

20 In forward biasing of the *p-n* junction **[CBSE AIPMT 2011]**
(a) the positive terminal of the battery is connected to *n*-side and the depletion region becomes thin
(b) the positive terminal of the battery is connected to *n*-side and the depletion region becomes thick
(c) the positive terminal of the battery is connected to *p*-side and the deplection region become thin
(d) the positive terminal of the battery is connected to *p*-side and the depletion region becomes thick

Ans. *(c)*
In forward biasing of *p-n* junction, the positive terminal of the battery is connected to *p*-side and the deplection region becomes thin.

21 Which one of the following statement is false?
[CBSE AIPMT 2010]
(a) ure Si doped with trivalent impurities gives a *p*-type semiconductor
(b) Majority carriers in a *n*-type semiconductor are holes
(c) Minority carriers in a *p*-type semiconductor are electrons
(d) The resistance of intrinsic semiconductor decreases with increase of temperature.

Ans. *(b)*
p-type semiconductor are obtained by adding a small amount of trivalent impurity to a pure sample of semiconductor (Ge).
Majority charge carriers—holes
Minority charge carriers—electrons
n-type semiconductor are obtained by adding a small amount of pentavalent impurity to a pure sample of semiconductor (Ge).
Majority charge carriers—electrons
The resistance of intrinsic semiconductors decreases with increase of temperature.

22 Sodium has body centred packing. Distance between two nearest atoms is 3.7 Å. The lattice parameter is **[CBSE AIPMT 2009, 1999]**
(a) 6.8 Å (b) 4.3 Å (c) 3.0 Å (d) 8.6 Å

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Ans. *(b)*

Neighbour distance of a body centred cubic cell $d = \frac{\sqrt{3}}{2}a$, where a is the lattice parameter.

$\Rightarrow \quad 3.7 = \frac{\sqrt{3}a}{2}$

or $\quad a = \frac{2 \times 3.7}{\sqrt{3}} = 4.3$ Å

23 A *p-n* photodiode is fabricated from a semiconductor with a band gap of 2.5 eV. It can detect a signal of wavelength **[CBSE AIPMT 2009]**

(a) 6000 Å (b) 4000 nm
(c) 6000 nm (d) 4000 Å

Ans. *(d)*

Energy, $\quad E = h\nu = h\frac{c}{\lambda}$

$\Rightarrow \quad \lambda = \frac{hc}{E}$

Substituting the values of h, c and E in the above equation

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{2.5 \times 1.6 \times 10^{-19}}$$

$$= 5000 \text{ Å}$$

As $\quad 4000 \text{ Å} < 5000 \text{ Å}$

Signal of wavelength 4000 Å can be detected by the photodiode.

24 A *p-n* photodiode is made of a material with a band gap of 2.0 eV. The minimum frequency of the radiation that can be absorbed by the material is nearly **[CBSE AIPMT 2008]**

(a) 10×10^{14} Hz (b) 5×10^{14} Hz
(c) 1×10^{14} Hz (d) 20×10^{14} Hz

Ans. *(b)*

Let the energy of radiation falling on the *p-n* photodiode be $E = h\nu$

The minimum energy required $= 2eV$

$\therefore \quad 2eV = h\nu$

$\therefore \quad \nu = \frac{2eV}{h}$

$$= \frac{2 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}}$$

$$= 5 \times 10^{14} \text{ Hz}$$

25 If the lattice parameter for a crystalline structure is 3.6 Å, then the atomic radius in fcc crystals is **[CBSE AIPMT 2008]**

(a) 1.81 Å (b) 2.10 Å
(c) 2.92 Å (d) 1.27 Å

Ans. *(d)*

For 'fcc' structure, $r = \frac{a}{2\sqrt{2}}$

where r = radius of the atom in the packing

a = edge length of the cube

Here, $a = 3.6$ Å

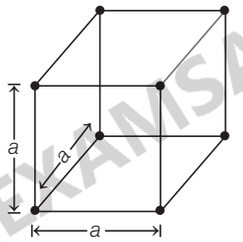
$\therefore \quad r = \frac{3.6}{2 \times 1.4} = 1.27$ Å

26 For a cubic crystal structure which one of the following relations indicating the cell characteristic is correct ? **[CBSE AIPMT 2007]**

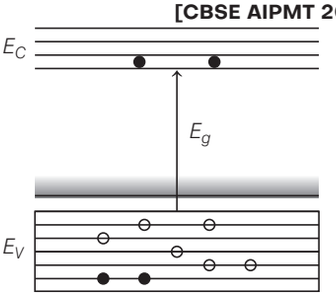
(a) $a \neq b \neq c$ and $\alpha \neq \beta$ and $\gamma \neq 90°$
(b) $a \neq b \neq c$ and $\alpha \neq \beta = \gamma = 90°$
(c) $a = b = c$ and $\alpha \neq \beta \neq \gamma = 90°$
(d) $a = b = c$ and $\alpha = \beta = \gamma = 90°$

Ans. *(d)*

In cubic crystals, the crystal axes are perpendicular to one another ($\alpha = \beta = \gamma = 90°$) and the repetitive interval is the same along the three axes ($a = b = c$).



27 In the energy band diagram of a material shown below, the open circles and filled circles denote holes and electrons respectively. The material is a/an **[CBSE AIPMT 2007]**



(a) *p*-type semiconductor
(b) insulator
(c) metal
(d) *n*-type semiconductor

Ans. *(a)*

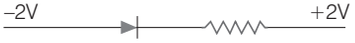
Since in the given diagram. we see that there are more number of holes so it is '*p*' type semiconductor.

28 A forward biased diode is **[CBSE AIPMT 2006]**

Ans.

(a)

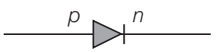
(b)

(c) 

(d)

Ans. *(d)*

The *p-n* junction diode can be shown as



If *p*-side of *p-n* junction diode is given more positive potential or positive terminal of the battery and *n*-side is connected to less potential or one terminal of battery, then it is forward biased.

In option (d), *p*-side is at 0 V and *n*-side at –2 V, so *p* is at higher potential. Hence, it is forward biased.

p-n junction diode is mainly used as a rectifier.

29 Copper has face-centered cubic (fcc) lattice with interatomic spacing equal to 2.54 Å. The value of lattice constant for this lattice is **[CBSE AIPMT 2005]**

(a) 1.27 Å
(b) 5.08 Å
(c) 2.54 Å
(d) 3.59 Å

Ans. *(d)*

Interatomic spacing for a fcc lattice is given by

$$r = \left[\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 + (0)^2\right]^{1/2} = \frac{a}{\sqrt{2}}$$

where, a being lattice constant.

$\therefore \quad a = \sqrt{2}r = \sqrt{2} \times 2.54$

$= 3.59$ Å

Interatomic spacing is just the nearest neighbours distance.

30 Choose only false statement from the following **[CBSE AIPMT 2005]**

(a) Substances with energy gap of the order of 10 eV are insulators
(b) The conductivity of a semiconductor increases with increases in temperature
(c) In conductors the valence and conduction bands may overlap

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(d) The resistivity of a semiconductor increases with increase in temperature

Ans. *(d)*

(a) In insulators, energy gap is of the order of 5 to 10 eV and it is practically impossible to impart this much amount of energy to the electrons in valence band so as to jump to conduction band.

So, choice (a) is correct.

(b) In semiconductors, with the rise in temperature more electrons from valence band jump to conduction band and this results in increase in conductivity. So, choice (b) is correct.

(c) In conductors, the conduction band is either partially filled or the conduction band overlaps on the valence band. So, choice (c) is correct.

(d) In semiconductor, resistivity decreases with increase in temperature.

So, choice (d) is wrong.

31 Zener diode is used for **[CBSE AIPMT 2005]**

(a) producing oscillations in an oscillator
(b) amplification
(c) stabilisation
(d) rectification

Ans. *(c)*

Zener diode is a silicon crystal diode having an unusual reverse current characteristic which is particularly suitable for voltage regulating purposes or voltage stabilisation purposes.

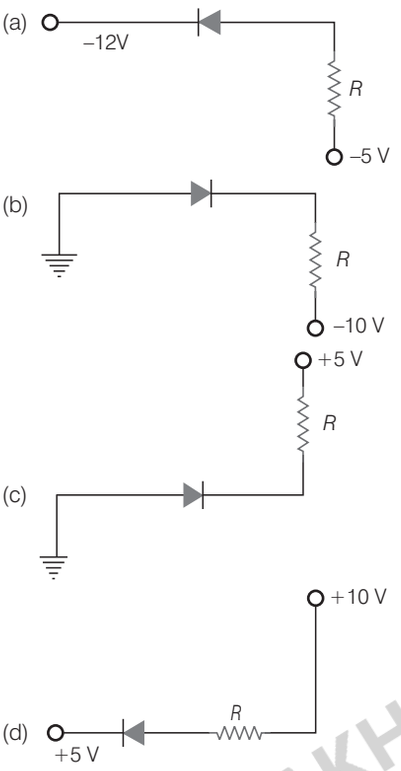
32 Application of a forward bias to a *p-n* junction **[CBSE AIPMT 2005]**

(a) increases the number of donors on the *n*-side
(b) increases the electric field in the depletion zone
(c) increases the potential difference across the depletion zone
(d) widens the depletion zone

Ans. *(a)*

On applying forward bias to a *p-n* junction diode, it increases number of donor on the *n*-side and decreases potential barrier. It also decreases electric field of depletion layer.

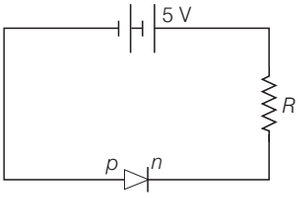
33 Of the diodes shown in the following diagrams, which one is reverse biased? **[CBSE AIPMT 2004]**



Ans. *(c)*

When a battery is connected to junction diode with *p*-side connected to negative terminal or lower potential and *n*-side to the positive terminal or higher potential, the junction diode is reverse biased.

The circuit shown in figure can be redrawn as



In the option (c), the *p*-end of the diode is connected to negative terminal of the battery, so the diode has been reverse biased.

34 In a *p-n* junction photo cell, the value of the photo-electromotive force produced by monochromatic light is proportional to **[CBSE AIPMT 2004]**

(a) the barrier voltage at the *p-n* junction
(b) the intensity of the light falling on the cell
(c) the frequency of the light falling on the cell
(d) the voltage applied at the *p-n* junction

Ans. *(b)*

In a photoconductive cell, when monochro- matic light is incident on the transparent metallic film, a force produced called the photo electromotive force, stimulates the emission of an electric current where photovoltaic action creates a potential difference between two points.

The magnitude of this current depends upon the intensity of incident light. Hence, photo electromotive force produced by monochromatic light is proportional to the intensity of light falling on the cell.

35 The peak voltage in the output of a half-wave diode rectifier fed with a sinusoidal signal without filter is 10 V. The DC component of the output voltage is **[CBSE AIPMT 2004]**

(a) $\frac{10}{\sqrt{2}}$ V (b) $\frac{10}{\pi}$ V
(c) 10 V (d) $\frac{20}{\pi}$ V

Ans. *(b)*

The output DC component of half wave rectifier is given by

$$V_{output} = \frac{\text{peak voltage}}{\pi} = \frac{10}{\pi}\text{ V}$$

36 In semiconductors at a room temperature **[CBSE AIPMT 2004]**

(a) the valence band is partially empty and the conduction band is partially filled
(b) the valence band is completely filled and the conduction band is partially filled
(c) the valence band is completely filled
(d) the conduction band is completely empty

Ans. *(a)*

The energy band scheme of semiconductors is shown here.

In semiconductors, valence band and conduction band are separated by an energy gap called the forbidden energy gap. It is very small. At room temperature some electrons in valence band acquire thermal energy.

This energy is more than forbidden energy gap E_g, thus they jump into the conduction band and leave their vacancy in the valence band which act as holes.

Hence, at room temperature valence band is partially empty and conduction band is partially filled.

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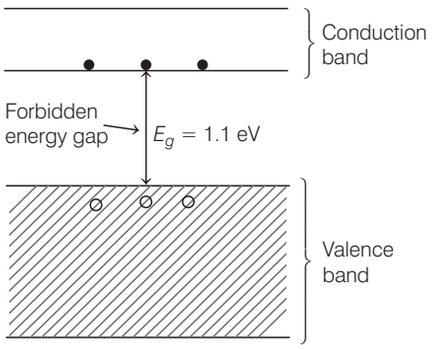


37 If a full wave rectifier circuit is operating from 50 Hz mains, the fundamental frequency in the ripple will be **[CBSE AIPMT 2003]**

(a) 70.7 Hz (b) 100 Hz
(c) 25 Hz (d) 59 Hz

Ans. *(b)*

For full wave rectifier,

Ripple frequency = 2 × input frequency
= 2 × 50
= 100 Hz

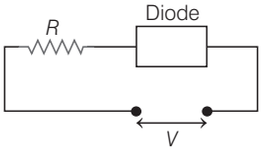
38 Barrier potential of a *p-n* junction diode does not depend on **[CBSE AIPMT 2003]**

(a) forward bias
(b) doping density
(c) diode design
(d) temperature

Ans. *(c)*

Barrier potential does not depend on diode design while it depends on temperature, doping density and forward biasing.

39 For a given circuit of ideal *p-n* junction diode, which of the following is correct? **[CBSE AIPMT 2002]**



(a) In forward biasing the voltage across R is V
(b) In reverse biasing the voltage across R is V
(c) In forward biasing the voltage across R is $2V$
(d) In reverse biasing the voltage across R is $2V$

Ans. *(a)*

In forward biasing, the diode conducts. For ideal junction diode, the forward resistance is zero. Therefore, entire applied voltage occurs across resistance R

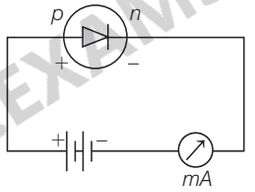
While in reverse biasing, the diode does not conduct, so it has infinite resistance. Thus, voltage across R is zero in reverse biasing.

40 For conduction in a *p-n* junction, the biasing is **[CBSE AIPMT 2002]**

(a) high potential on *n*-side and low potential on *p*-side
(b) high potential on *p*-side and low potential on *n*-side
(c) same potential on both *p* and *n*-sides
(d) undetermined

Ans. *(b)*

For conduction in a *p-n* junction, it should be forward biased because it offers minimum resistance to the flow of current. For this *p*-side must be connected to positive terminal (higher potential) and *n*-side must be connected to negative terminal (lower potential). Figure below shows the *p-n* junction in a conducting state (forward biased condition)



41 The number of atoms per unit cell in bcc lattice is **[CBSE AIPMT 2002]**

(a) 1 (b) 2
(c) 4 (d) 9

Ans. *(b)*

Number of atoms per unit cell is given by

$$N = N_b + \frac{N_f}{2} + \frac{N_c}{8}$$

where N_b = number of atoms centred in the body

N_f = number of atoms centred in the face

N_c = number of atoms centred at the corners

For bcc structure,

$$N_b = 1, \quad N_f = 0$$

and $N_c = 8$

$$\therefore \quad N = 1 + \frac{0}{2} + \frac{8}{8} = 2$$

42 In bcc structure of lattice constant a, the minimum distance between atoms is **[CBSE AIPMT 2001]**

(a) $\frac{\sqrt{3}}{2}a$ (b) $\sqrt{2}a$ (c) $\frac{a}{\sqrt{2}}$ (d) $\frac{a}{2}$

Ans. *(a)*

In a bcc structure, the position vectors of the nearest neighbours of the origin are

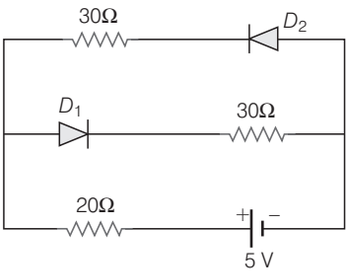
$$\left(\pm\frac{a}{2}\hat{\mathbf{i}}, \pm\frac{a}{2}\hat{\mathbf{j}}, \pm\frac{a}{2}\hat{\mathbf{k}}\right).$$

The distance between any two nearest neighbours is given but the resultant of above position vector is

$$\sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2} = \sqrt{\frac{3a^2}{4}}$$

$$= \frac{\sqrt{3}}{2}a$$

43 If internal resistance of cell is negligible, then current flowing through the circuit is **[CBSE AIPMT 2001]**



(a) $\frac{3}{50}$ A (b) $\frac{5}{50}$ A
(c) $\frac{4}{50}$ A (d) $\frac{2}{50}$ A

Ans. *(b)*

In the circuit, diode D_1 is forward biased and diode D_2 is reverse biased.
Therefore, no current flows in the arm containing D_2 and all of the current flows through arm containing D_1.

Thus, current flowing through the circuit is given by

$$I = \frac{V}{R_{eq}} = \frac{5}{20+30} = \frac{5}{50}\text{ A}$$

$$[\because R_{eq} = 20\ \Omega + 30\ \Omega]$$

44 Si and Cu are cooled to a temperature of 300 K, then resistivity **[CBSE AIPMT 2001]**

(a) for Si increases and for Cu decreases
(b) for Cu increases and for Si decreases
(c) decreases for both Si and Cu
(d) increases for both Si and Cu

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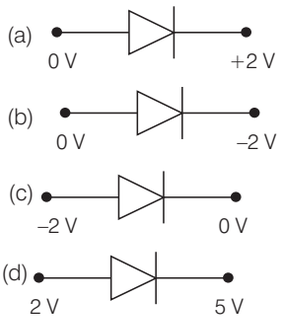
Ans. *(a)*

Resistivity of a metal is directly proportional to temperature because its temperature cofficient is positive and resistivity of semiconductor is inversely proportional to temperature. due to its negative temperature coefficient. This implies that with decrease in temperature, resistivity of metal decreases while that of semiconductor increases.

Here, Si is a semiconductor and Cu is a metal. So, resistivity of Si increases but that of Cu decreases.

45 In which of the following figures, junction diode is forward biased ? **[CBSE AIPMT 2000]**



Ans. *(b)*

For forward biasing of *p*-*n* junction, *p*-side should be at higher potential than *n*-side. Now we apply this rule to the four options.

(a) Here, *p*-side is at lower potential (0 V) and *n*-side at higher potential (2 V). So, this diode is not forward biased.

(b) Here, *p*-side is at higher potential (0 V) and *n*-side at lower potential (–2 V). So, this diode is forward biased.

(c) Here, *p*-side is at lower potential (–2 V) and *n*-side at higher potential (0 V). So, this diode is not forward biased.

(d)Here *p*-side is at lower potential (2 V) and *n*-side at higher potential (5 V). So, this is not forward biased.

Hence, choice (b) is correct.

46 In *p*-type semiconductor, the majority charge carriers are **[CBSE AIPMT 1999]**

(a) holes (b) electrons
(c) protons (d) neutrons

Ans. *(a)*

Semiconductors doped with acceptor atoms are called *p*-type semiconductors. The *p* stands for positive to imply that the holes are introduced into the valence band, which behave like positive charge carriers, greatly in number than the electrons in the conduction band.

In *p*-type semiconductors, holes are the majority carriers and electrons are the minority carriers.

47 In forward bias the width of depletion layer in a *p*-*n* junction diode **[CBSE AIPMT 1999]**

(a) increases
(b) decreases
(c) remains constant
(d) first increases then decreases

Ans. *(b)*

Since in forward biasing, negative of the battery is connected to *n*-type side, and the positive terminal of battery is connected to *p*-type side hence an electric field is created in direction opposite to the $\mathbf{E}$ in the potential barrier region. Thus, depletion layer of *p*-*n* junction diode decreases.

48 Depletion layer consists of **[CBSE AIPMT 1999]**

(a) electrons
(b) protons
(c) mobile charge carriers
(d) immobile ions

Ans. *(d)*

When a piece of *p*-type material is in contact with *n*-type material, then to bring Fermi level in a line, electrons in conduction band on *n*-type side travel across the junction and leave the positively ionised impurity atoms unneutralized. Consequently, there is a positively charged region adjacent to the junction in *n*-type material .

On *p*-type side, the electrons which have traversed the boundary recombine with positive holes in the valence band. Near to the junction on *p*-type side, there is a layer of unneutralised negatively ionised trivalent impurity which forms a negatively charged region. This region around the junction is called charge depletion region or space charge region.

49 In a junction diode, the holes are due to **[CBSE AIPMT 1999]**

(a) protons (b) extra electrons
(c) neutrons (d) missing electrons

Ans. *(d)*

In a junction diode, when electron jumps to conduction band from valence band due to thermal agitation or any other circumstances, then a vacancy is created in valence band which has positive charge equal to charge of electron in magnitude. This is called a hole.

Thus, holes in junction diode are due to missing electrons.

50 Which of the following when added as an impurity into silicon produces *n*-type semiconductor ? **[CBSE AIPMT 1999]**

(a) P (b) Al
(c) B (d) Mg

Ans. *(a)*

When pentavalent impurity is added to silicon then *n*-type semiconductor is formed. Out of given options, only phosphorus (P) is pentavalent, so it should be doped to silicon to make it *n*-type semiconductor.

51 A semiconducting device is connected in a series in circuit with a battery and a resistance. A current is allowed to pass through the circuit. If the polarity of the battery is reversed, the current drops to almost zero. The device may be **[CBSE AIPMT 1998]**

(a) a *p*-*n* junction
(b) an intrinsic semiconductor
(c) a *p*-type semiconductor
(d) an *n*-type semiconductor

Ans. *(a)*

We know that in forward biasing of *p*-*n* junction the current is of the order of milliampere while in reverse biasing the current is of the order of microampere (negligible). Thus, device is a *p*-*n* junction.

52 The cause of the potential barrier in a *p*-*n* diode is **[CBSE AIPMT 1998]**

(a) depletion of positive charges near the junction
(b) concentration of positive charges near the junction
(c) depletion of negative charges near the junction
(d) concentration of positive and negative charges near the junction

Ans. *(d)*

In a *p*-*n* junction diode, majority carriers are holes on *p*-side and electrons on *n*-side. Holes, thus diffuse to *n*-side and electrons to *p*-side. This diffusion causes a layer of positive charge in the

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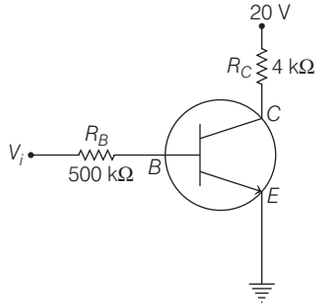
n-region and layer of negative charge in the *p*-region near the junction.

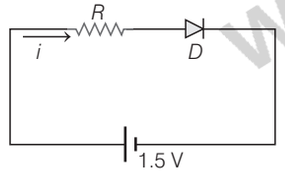
This double layer of opposite charge creates an electric field which exerts a force on the electrons and holes, against their diffusion. This electric field becomes strong enough as diffusion proceeds to stop it. In the equilibrium position, there is a barrier, for charge motion with the *n*-side at a higher potential than the *p*-side.

The junction region has a very low density of either *p* or *n*-type carriers, because of inter diffusion. It is called depletion region.



53 The diode used in the circuit shown in the figure has a constant voltage drop of 0.5 V at all currents and a maximum power rating of 100 milliwatt. What should be the value of the resistor *R*, connected in series with the diode, for obtaining maximum current *i* ?

[CBSE AIPMT 1997]



(a) 200 Ω (b) 6.67 Ω
(c) 5 Ω (d) 1.5 Ω

Ans. *(c)*

Current in circuit $i = \frac{P}{V_d} = \frac{100 \times 10^{-3}}{0.5}$

[V_d = voltage drop across diode]

$= 200 \times 10^{-3}$ A

Voltage across resistance *R*,

$V' = 1.5 - 0.5$

$= 1.0$ V

Thus, resistance $R = \frac{V'}{i}$

$= \frac{1}{200 \times 10^{-3}} = 5\ \Omega$

54 To obtain a *p*-type germanium semiconductor, it must be doped with **[CBSE AIPMT 1997]**

(a) phosphorus (b) indium
(c) antimony (d) arsenic

Ans. *(b)*

If a trivalent impurity is mixed in a pure (intrinsic) semiconductor, then it becomes a *p*-type semiconductor. As given indium is trivalent impurity so it must be doped to Ge or Si to make it *p*-type semiconductor.

55 When arsenic is added as an impurity to silicon, the resulting material is **[CBSE AIPMT 1996]**

(a) *n*-type semiconductor
(b) *p*-type semiconductor
(c) *n*-type conductor
(d) insulator

Ans. *(a)*

When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as *n*-type semiconductor. Arsenic (33) is pentavalent impurity. The addition of pentavalent impurity provides a large number of free electrons in the semiconductor crystal.

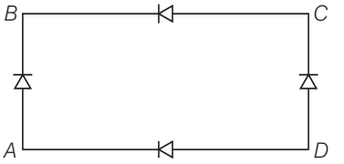
56 Which of the following, when added as an impurity, into the silicon, produces *n*-type semiconductor ? **[CBSE AIPMT 1995]**

(a) Phosphorus (b) Aluminium
(c) Magnesium (d) Both (b) and (c)

Ans. *(a)*

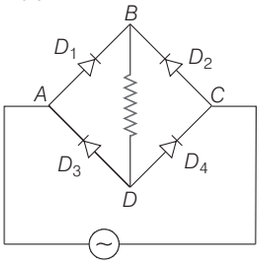
When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as *n*-type semiconductor. Phosphorus (P) is a pentavalent and silicon is a tetravalent. Therefore, when phosphorus is doped with Si, it forms a *n*-type semiconductor.

57 In figure the input is across the terminals *A* and *C* and the output is across *B* and *D*. Then the output is **[CBSE AIPMT 1994]**

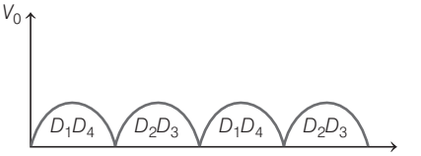


(a) zero
(b) same as the input
(c) half wave rectified
(d) full wave rectified

Ans. *(d)*



AC input is applied across *A* and *C* and output is taken across *BD*.



When positive cycle is fed to *AC*, D_1 and D_4 conduct, when negative cycle is fed to *AC*, D_3 and D_2 conduct in the same direction. Output across *BD* is thus full wave rectified.

58 When a *p*-*n* junction diode is reverse biased the flow of current across the junction is mainly due to **[CBSE AIPMT 1994]**

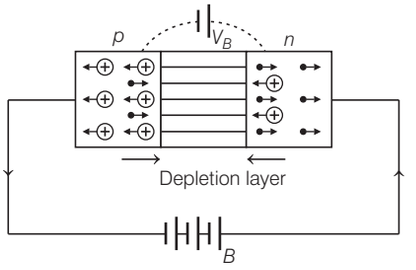
(a) diffusion of charges
(b) drift charges
(c) Depends on the nature of material
(d) Both drift and diffusion of charges

Ans. *(b)*

A *p*-*n* junction is said to be reverse biased, if the positive terminal of the external battery *B* is connected to *n*-side and the negative terminal to *p*-side of the *p*-*n* junction.

In reverse biasing, the reverse bias voltage supports the potential barrier V_B. Now the majority carriers are pulled away from the junction and the depletion region becomes thick.

There is no conduction across the junction due to majority carriers. However, a few minority carriers (holes in *n*-section and electrons in *p*-section) of *p*-*n* junction diode cross the junction after being accelerated by high reverse bias voltage. They constitute a current that flows in the opposite direction.



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So when *p-n* junction is reverse biased, the flow of current is due to drifting of minority charge carries across the junction.

59 A piece of copper and other of germanium are cooled from the room temperature to 80 K, then **[CBSE AIPMT 1993]**

(a) resistance in each will increase
(b) resistance in each will decrease
(c) the resistance of copper will increase while that of germanium will decrease
(d) the resistance of copper will decrease while that of germanium will increase

Ans. *(d)*

Semiconductor have negative temperature coefficient of resistance i.e. the resistance of a semiconductor decreases with the increase in temperature as no. of electrons increases in conduction bond. Copper has positive temperature coefficient of resistance, i.e. the resistance of copper increases with the increase in temperature due to the collision of electrons. Hence, at 80 K, the resistance of copper will decrease while that of germanium will increase.

60 Diamond is very hard, because **[CBSE AIPMT 1993]**

(a) it is covalent solid
(b) it has large cohesive energy
(c) high melting point
(d) insoluble in all solvents

Ans. *(b)*

The cohesive energy of solids is defined as the energy required for separating the condensed material into isolated free atoms.

The bond between two carbon atoms in diamond has a cohesive energy of 7.3 eV with respect to separated neutral atoms. Due to such high cohesive energy diamond is very hard.

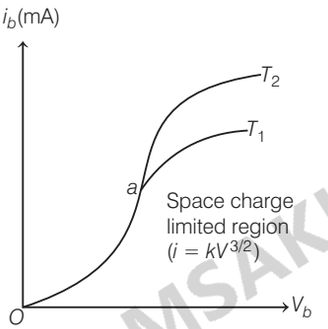
61 For an electronic valve, the plate current i and plate voltage V in the space charge limited region are related as **[CBSE AIPMT 1992]**

(a) i is proportional to $V^{3/2}$
(b) i is proportional to $V^{2/3}$
(c) i is proportional to V
(d) i is proportional to V^2

Ans. *(a)*

The most important characteristic of a vacuum diode is the plate characteristic which gives the relation between plate voltage and plate current for a given cathode temperature.

It may be noted from the plate characteristics that all the curves are coincident at low plate voltage where the negative space charge is most effective in limiting plate current. This low plate voltage region [region *oa* in figure] is known as space charge limited region. In this region, the plate current increases as the plate voltage is increased, because more positive plate attracts electrons from the space charge at a greater rate. In the space charge limited region the plate current is given by the relation $i = kV^{3/2}$



i.e. $i \propto V^{3/2}$

where, k is constant.

62 Which one of the following is the weakest kind of the bonding in solids ? **[CBSE AIPMT 1992]**

(a) Ionic (b) Metallic
(c) van der Waals' (d) Covalent

Ans. *(c)*

Many solids or crystals are composed of neutral atoms or molecules without any transferring, sharing or free movement of electrons. These solids remains bound by much weaker, short range attractive forces, known as 'van der Waals' forces. These forces arise as a result of fluctuations in the charge distributions of nearby molecules.

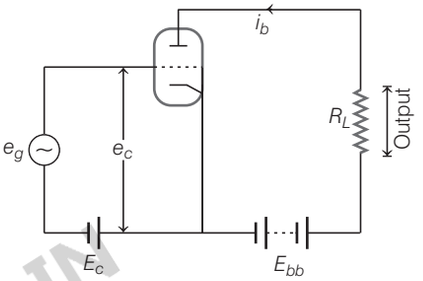
63 For amplification by a triode, the signal to be amplified is given to **[CBSE AIPMT 1992]**

(a) the cathode
(b) the grid
(c) the glass-envelope
(d) the anode

Ans. *(b)*

Figure shows the basic triode amplifier circuit. The weak signal e_g is applied in the grid circuit and useful output is obtained across the load R_L connected in the plate circuit. The bias battery E_C ensures the grid to be always negative w.r.t. cathode.

The weak signal voltage produces a large change in plate current. As the value of R_L is quite high, therefore a large voltage drop occurs across it. Thus, a weak signal applied in the grid circuit appears in the amplified form in the plate circuit.

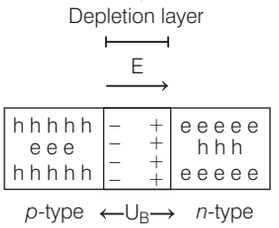


64 The depletion layer in the *p-n* junction region is caused by **[CBSE AIPMT 1991]**

(a) drift of holes
(b) diffusion of charge carriers
(c) migration of impurity ions
(d) drift of electrons

Ans. *(b)*

The accumulation of electric charges of opposite polarities in the two regions of the junction gives rise to an electric field between these region due to the diffusion of charge carriers. This electric field opposes further flow of electrons from the *n*-region to the *p*-region and that of holes from the *p*-region to *n*-region. This electric field sets a potential barrier V_B at the junction which opposes further diffusion of free charge carriers into opposite regions. In the vicinity of the junction, a region is created, which is devoid of free charge carriers and has immobile ions. This region in which no free charge carriers are available is called a depletion region. This is shown in figure.



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65 When a triode is used as an amplifier the phase difference between the input signal voltage and the output is **[CBSE AIPMT 1990]**

(a) zero (b) π
(c) $\frac{\pi}{2}$ (d) $\frac{\pi}{4}$

Ans. *(b)*

In the triode amplifier, there is a phase difference of 180° between the input (i.e. signal) voltage and output voltage. In other words, the positive half-cycle of the signal appears as amplified negative-half in the output while the negative half-cycle of the signal appears as amplified positive half in the output.

This is known as phase reversal. In other words, as the signal is increasing in the negative half-cycle, the output is increasing in the positive sense.

66 When *n*-type semiconductor is heated **[CBSE AIPMT 1989]**

(a) number of electrons increases while that of holes decreases
(b) number of holes increases while that of electrons decreases
(c) number of electrons and holes remain same
(d) number of electrons and holes increases equally

Ans. *(d)*

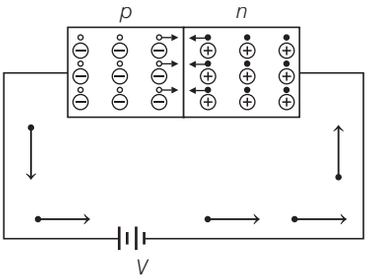
When *n*-type semiconductor is heated a few hole-electron pairs generate. When a free electron is produced then simultaneously a hole is also produced. Thus no. of elecrons and holes both increases equally.

67 *p-n* junction is said to be forward biased, when **[CBSE AIPMT 1988]**

(a) the positive pole of the battery is joined to the *p*-semiconductor and negative pole to the *n*-semiconductor
(b) the positive pole of the battery is joined to the *n*-semiconductor and negative pole to the *p*-semiconductor
(c) the positive pole of the battery is connected to *n*-semiconductor and *p*-semiconductor
(d) a mechanical force is applied in the forward direction

Ans. *(a)*

When external voltage is applied to the junction in such a direction that it cancels the potential barrier, or decreases potential barrier thus permitting current flow, it is called forward biasing. To apply forward bias, connect positive terminal of the battery to *p*-type and negative terminal to *n*-type as shown in figure.



68 At absolute zero, Si acts as **[CBSE AIPMT 1988]**

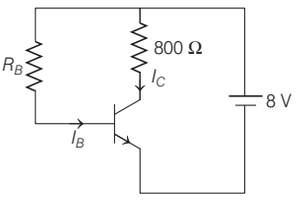
(a) non-metal (b) metal
(c) insulator (d) None of these

Ans. *(c)*

Semiconductors have negative temperature coefficient of resistance, i.e. the resistance of a semiconductor decreases with the increase in temperature and *vice-versa*. Silicon is actually an insulator at absolute zero of temperature but it becomes a good conductor at high temperatures. Because on giving temperatures to semiconductor some of the electron jumps from valence band to conduction band.

TOPIC 2
Transistors

69 A *n-p-n* transistor is connected in common emitter configuration (see figure) in which collector voltage drop across load resistance (800Ω) connected to the collector circuit is 0.8 V. The collector current is **[NEET (Oct.) 2020]**



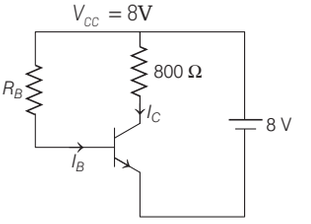
(a) 2 mA (b) 0.1 mA (c) 1 mA (d) 0.2 mA

Ans. *(c)*

According to given circuit diagram.

$R_C = 800\ \Omega$

$V_{CC} = 8\text{V}$



Voltage drop across R_C,

$V_C = 0.8\text{V}$

$\Rightarrow I_C R_C = 0.8$

$I_C = \frac{0.8}{R_C} = \frac{0.8}{800} = 10^{-3}\text{A} = 1\,\text{mA}$

70 For transistor action, which of the following statements is correct? **[NEET (Sep.) 2020]**

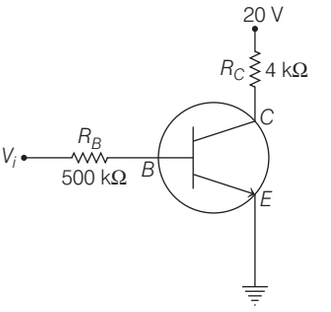
(a) Base, emitter and collector regions should have same size.
(b) Both emitter junction as well as the collector junction are forward biased.
(c) The base region must be very thin and lightly doped.
(d) Base, emitter and collector regions should have same dopping concentrations.

Ans. *(c)*

In case of transistor action, base region is thin and lightly dopped. While, emitter region is heavily dopped and collector region is moderately dopped. Also, the size of collector is slightly more than the size of emitter.

Hence, option (c) is correct.

71 In the circuit shown in the figure, the input voltage V_i is 20 V, $V_{BE} = 0$ and $V_{CE} = 0$. The values of I_B, I_C and β are given by **[NEET 2018]**



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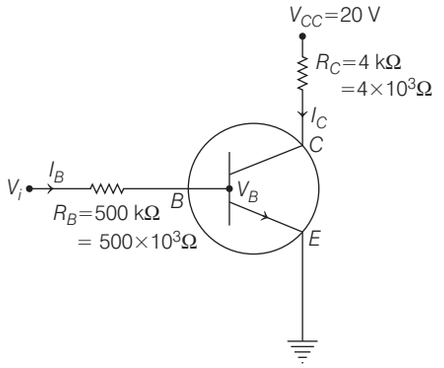
(a) $I_B = 20\,\mu A,\ I_C = 5\,mA,\ \beta = 250$
(b) $I_B = 25\,\mu A,\ I_C = 5\,mA,\ \beta = 200$
(c) $I_B = 40\,\mu A,\ I_C = 10\,mA,\ \beta = 250$
(d) $I_B = 40\,\mu A,\ I_C = 5\,mA,\ \beta = 125$

Ans. *(d)*

Given, $V_{BE} = 0$ V, $V_{CE} = 0$ V and $V_i = 20$ V



Applying Kirchhoff's law to the base-emitter loop, we get

$$V_i = I_B R_B + V_{BE}$$

Substituting the values, we get

$$20 = I_B \times (500 \times 10^3) + 0$$

$$\Rightarrow \quad I_B = \frac{20}{500 \times 10^3} = 0.04 \times 10^{-3}$$

$$= 40 \times 10^{-6} = 40\,\mu A \qquad ...(i)$$

Similarly, $V_{CC} = I_C R_C + V_{CE}$

Substituting the given values, we get

$$20 = I_C \times (4 \times 10^3) + 0$$

$$\Rightarrow \quad I_C = \frac{20}{4 \times 10^3} = 5 \times 10^{-3} = 5\,mA \qquad ...(ii)$$

Current gain is given as

$$\beta = \frac{I_C}{I_B}$$

Substituting the value of I_B and I_C from Eqs. (i) and (ii), we get

$$\Rightarrow \quad \beta = \frac{5 \times 10^{-3}}{40 \times 10^{-6}} = 0.125 \times 10^3$$

$$= 125$$

72 In a common emitter transistor amplifier, the audio signal voltage across the collector is 3 V. The resistance of collector is 3 kΩ. If current gain is 100 and the base resistance is 2 kΩ, the voltage and power gain of the amplifier is **[NEET 2017]**

(a) 200 and 1000 (b) 15 and 200
(c) 150 and 15000 (d) 20 and 2000

Ans. *(c)*

Collector current $i_C = \frac{V}{R} = \frac{3}{3 \times 10^3} = 10^{-3}$ A

Now base current

$$i_B = \frac{i_C}{B} = \frac{10^{-3}}{100} = 10^{-5}\ A$$

As, voltage $V_{in} = i_B R_B$

$$\therefore \quad V_{in} = 10^{-5} \times 2 \times 10^3$$

$$= 2 \times 10^{-2} \text{ volts}$$

So, voltage gain $A_V = \frac{V_{out}}{V_{in}} = \frac{3}{2 \times 10^{-2}}$

$= 150$

Power gain $= A_V \times \beta = 150 \times 100 = 15000$

73 A *n-p-n* transistor is connected in common emitter configuration in a given amplifier. A load resistance of 800 Ω is connected in the collector circuit and the voltage drop across it is 0.8V. If the current amplification factor is 0.96 and the input resistance of the circuits is 192 Ω, the voltage gain and the power gain of the amplifier will respectively be **[NEET 2016]**

(a) 3.69, 3.84 (b) 4, 4
(c) 4, 3.69 (d) 4, 3.84

Ans. *(d)*

Given, resistance across load, $R_L = 800\ \Omega$

Voltage drop across load, $V_L = 0.8$ V

Input resistance of circuit, $R_i = 192\ \Omega$.

Collector current is given by,

$$I_C = \frac{V_L}{R_L} = \frac{0.8}{800} = \frac{8}{8000} = 1\,mA$$

$\because$ Current amplification

$$= \frac{\text{Output current}}{\text{Input current}}$$

$$= \frac{I_C}{I_B} = 0.96 \Rightarrow I_B = \frac{1\,mA}{0.96}$$

$\because$ Voltage gain,

$$A_V = \frac{V_L}{V_{in}} = \frac{V_L}{I_B R_i} = \frac{0.8 \times 0.96}{10^{-3} \times 192} = 4$$

$$\Rightarrow \quad A_V = 4$$

and Power gain,

$$A_P = \frac{I_C^2 R_L}{I_B^2 R_i} = \left(\frac{I_C}{I_B}\right)^2 . \frac{R_L}{R_i} = (0.96)^2 \times \frac{800}{192}$$

$$A_P = 3.84$$

74 For CE transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 4 V. If the current amplification factor of the transistor is 100 and the base resistance is I kΩ, then the input signal voltage is **[NEET 2016]**

(a) 10 mV (b) 20 mV
(c) 30 mV (d) 15 mV

Ans. *(b)*

Key Idea Voltage amplification is

$$A_V = \beta \frac{R_{out}}{R_{in}} = \frac{(V_{out})_{AC}}{(V_{in})_{AC}}$$

Given, collector resistance $= R_{out} = 2\,k\Omega$
Current amplification factor, $\beta = 100$
Base resistance, $R_{in} = 1\,k\Omega$
Output signal voltage $= 4$ V
Putting all the values in given equation, we get

$$A_V = \beta \frac{R_{out}}{R_{in}} = 100 \times \frac{2\,k\Omega}{1\,k\Omega} \Rightarrow A_V = 200$$

Now, $A_V = \frac{(V_{out})_{AC}}{(V_{in})_{AC}} = 200$

$$\Rightarrow \quad (V_{in})_{AC} = \frac{4}{200} = 20\,mV$$

75 The input signal given to a *CE* amplifier having a voltage gain of 150 is $V_i = 2\cos\left(15t + \frac{\pi}{3}\right)$. The corresponding output signal will be **[CBSE AIPMT 2015]**

(a) $300\cos\left(15\,t + \frac{\pi}{3}\right)$
(b) $75\cos\left(15\,t + \frac{2\pi}{3}\right)$
(c) $2\cos\left(15\,t + \frac{5\pi}{3}\right)$ (d)
$300\cos\left(15\,t + \frac{4\pi}{3}\right)$

Ans. *(d)*

Input signal of a CE amplifer,

$$V_{in} = 2\cos\left(15t + \frac{\pi}{3}\right)$$

Voltage gain $A_v = 150$

As CE amplifier gives phase difference of π between input and output signals.

So, $A_v = \frac{V_0}{V_{in}} \Rightarrow V_0 = A_v V_{in}$

$$V_0 = 150 \times 2\cos\left(15t + \frac{\pi}{3} + \pi\right)$$

$$V = 300\cos\left(15t + \frac{4\pi}{3}\right)$$

76 In a common emitter (CE) amplifier having a voltage gain *G*, the transistor used has transconductance 0.03 mho and current gain 25. If the above transistor is replaced with another one with transconductance 0.02 mho and current gain 20, the voltage gain will **[NEET 2013]**

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(a) $\frac{2}{3}G$ (b) $1.5\,G$

(c) $\frac{1}{3}G$ (d) $\frac{5}{4}G$

Ans. *(a)*

As $A_v = \beta\frac{R_L}{R_i}$ or $G = \left(\frac{\beta}{R_i}\right)R_L$

$\Rightarrow G = g_m R_L \Rightarrow G \propto g_m$

$\left[\because g_m = \frac{\Delta I_c}{\Delta V_B} = \frac{\Delta I_c}{\Delta I_B R_i}\right]$

$\left[\because g_m = \frac{\beta}{R_i}\right]$

$\therefore \quad \frac{G_2}{G_1} = \frac{g_{m_2}}{g_{m_1}} \Rightarrow G_2 = \frac{0.02}{0.03}\times G$

So, voltage gain, $G_2 = \frac{2}{3}G$

77 In a CE transistor amplifier, the audio signal voltage across the collector resistance of $2\,k\Omega$ is 2V. If the base resistance is $1\,k\Omega$ and the current amplification of the transistor is 100, the input signal voltage is **[CBSE AIPMT 2012]**

(a) 0.1 V (b) 1.0 V (c) 1 mV (d) 10 mV

Ans. *(d)*

Current amplification factor

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Collector resistance

$$\Delta I_C = \frac{2V}{2\times 10^3\,\Omega} = 1\times 10^{-3}\,A$$

Base current

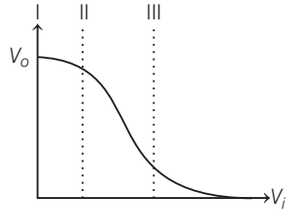
$$\Delta I_B = \frac{V_B}{R_B} = \frac{V_B}{1\times 10^3} = V_B\times 10^{-3}$$

Given, $\beta = 100$

Now, $100 = \frac{10^{-3}}{V_B\times 10^{-3}}$

$V_B = \frac{1}{100}\,V = 10\,mV$

78 Transfer characteristic [output voltage (V_o) *vs* input voltage (V_i)] for a base biased transistor in CE configuration is as shown in the figure. For using transistor as a switch, it is used **[CBSE AIPMT 2012]**



(a) in region III

(b) both in region (I) and (III)

(c) in region II

(d) in region I

Ans. *(b)*

For using transistor as a switch, it is used in cut-off state and saturation state only.

79 A common emitter amplifier has a voltage gain of 50, an input impedance of $100\,\Omega$ and an output impedance of $200\,\Omega$. The power gain the amplifier is **[CBSE AIPMT 2010, 2007]**

(a) 500 (b) 1000

(c) 1250 (d) 50

Ans. *(c)*

Concept AC power gain

$$= \frac{\text{change in output power}}{\text{change in input power}}$$

$$= \frac{\Delta V_c \times \Delta i_c}{\Delta V_i \times \Delta i_b}$$

$$= \left(\frac{\Delta V_c}{\Delta V_i}\right)\times\left(\frac{\Delta i_c}{\Delta i_b}\right) = A_V \times \beta_{AC}$$

where, A_V is voltage gain and $(\beta)_{AC}$ is AC current gain. Also,

$A_V = \beta_{AC} \times$ resistance gain $\left(= \frac{R_o}{R_i}\right)$

Voltage gain $= \beta \times$ impedance gain

$\Rightarrow \quad 50 = \beta \times \frac{200}{100} \Rightarrow \beta = 25$

Also, power gain $= \beta^2 \times$ impedance gain

$= 25^2 \times \frac{200}{100} = 1250$

80 A transistor is operated in common-emitter configuration at $V_c = 2$ volt such that a change in the base current from $100\,\mu A$ to $200\,\mu A$ produces a change in the collector current from 5 mA to 10 mA. The current gain is **[CBSE AIPMT 2009]**

(a) 75 (b) 100

(c) 150 (d) 50

Ans. *(d)*

For a transistor

$I_E = I_B + I_C$

where I_E = emitter current

I_B = base current

I_C = collector current

and current gain $\beta = \frac{\Delta I_C}{\Delta I_B}$

Here, $\Delta I_C = 10\times 10^{-3} - 5\times 10^{-3}$

$= 5\times 10^{-3}\,A$

$\Delta I_B = 200\times 10^{-6} - 100\times 10^{-6}$

$= 100\times 10^{-6}\,A$

$\therefore \quad \beta = \frac{5}{100}\times 1000 = 50$

81 The voltage gain of an amplifier with 9% negative feedback is 10. The voltage gain without feedback will be **[CBSE AIPMT 2008]**

(a) 90 (b) 10 (c) 1.25 (d) 100

Ans. *(d)*

Voltage gain $= \frac{A_V}{1+\beta A_V}$

$10 = \frac{A_V}{1+\frac{9}{100}A_V}$

$A_V = \frac{10}{0.1} = 100$

82 A transistor is operated in common emitter configuration at constant collector voltage $V_c = 1.5\,V$ such that a change in the base current from $100\,\mu A$ to $150\,\mu A$ produces a change in the collector current from 5 mA to 10 mA. The current gain (β) is **[CBSE AIPMT 2006]**

(a) 67 (b) 75 (c) 100 (d) 50

Ans. *(c)*

AC current gain β is defined as the ratio of the collector to the base current at constant collector voltage,

$$\beta = \left(\frac{\Delta i_c}{\Delta i_b}\right)_{V_c}$$

Given, $\Delta i_c = 10\,mA - 5\,mA = 5\,mA$

$\Delta i_b = 150\,\mu A - 100\,\mu A = 50\,\mu A$

$\therefore \quad \beta = \frac{5\,mA}{50\times 10^{-3}\,mA} = 100$

In common emitter amplifier, the output voltage signal is 180° out of phase with the input voltage signal

83 A transistor-oscillator using a resonant circuit with an inductor L (of negligible resistance) and a capacitor C in series produce oscillations of frequency f. If L is doubled and C is changed to $4\,C$, the frequency will be **[CBSE AIPMT 2006]**

(a) $\frac{f}{4}$ (b) $8\,f$ (c) $\frac{f}{2\sqrt{2}}$ (d) $\frac{f}{2}$

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Ans. *(c)*

In a series LC-circuit, frequency of LC-oscillations is given by

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad f \propto \frac{1}{\sqrt{LC}}$$

Considering two cases of L and C,

$$\frac{f_1}{f_2} = \sqrt{\frac{L_2C_2}{L_1C_1}}$$

Given, $L_1 = L, C_1 = C, L_2 = 2L, C_2 = 4C, f_1 = f$

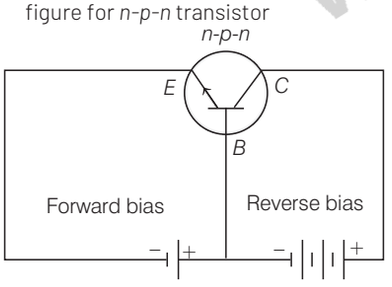
$$\therefore \quad \frac{f}{f_2} = \sqrt{\frac{2L \times 4C}{LC}} = \sqrt{8} \Rightarrow f_2 = \frac{f}{2\sqrt{2}}$$

84 A n-p-n transistor conducts when **[CBSE AIPMT 2003]**

(a) collector is positive and emitter is at same potential as the base
(b) both collector and emitter are negative with respect to the base
(c) both collector and emitter are positive with respect to the base
(d) collector is positive and emitter is negative with respect to the base

Ans. *(d)*

For amplifying action of a transistor, emitter-base junction is always forward biased while base-collector junction is reverse biased. For forward biasing of emitter-base junction in n-p-n transistor, left n-side i.e. emitter should be connected to negative terminal and p-side (base) should be connected to positive terminal of the battery. On the other hand, in right side, n-side (collector) should be connected to positive terminal of the battery to make base-collector junction reverse biased. The whole situation is shown in the figure for n-p-n transistor



$E \rightarrow$ Emitter
$B \rightarrow$ Base
$C \rightarrow$ Collector

85 For a transistor $\frac{i_c}{i_e} = 0.96$, the current gain in common-emitter configuration is **[CBSE AIPMT 2002]**

(a) 6 (b) 12 (c) 24 (d) 48

Ans. *(c)*

Given that the current gain in common base emitter is

$$\frac{i_c}{i_e} = \text{Current gain}\,(\alpha) = 0.96$$

So, current gain in common emitter configuration is

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = \frac{0.96}{0.04} = 24$$

The current gain β in common emitter mode is very large as compared to the current gain α in common base mode. This is why a transistor is always used as an amplifier in the CE mode.

86 In a common-base configuration of a transistor $\frac{\Delta i_c}{\Delta i_e} = 0.98$, then current gain in common emitter configuration of transistor will be **[CBSE AIPMT 2001]**

(a) 49 (b) 98
(c) 4.9 (d) 24.5

Ans. *(a)*

The current gain (α) in common-base configuration is

$$\alpha = \frac{\Delta i_c}{\Delta i_e} \quad \left[\begin{array}{l}\text{at constant voltage across}\\ \text{collector base junction}\end{array}\right]$$

$$= 0.98$$

The current gain in common-emitter configuration

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \frac{0.98}{0.02} = 49$$

87 If α and β are current gains in common-base and common-emitter configurations of a transistor, then β is equal to **[CBSE AIPMT 2000]**

(a) $\frac{1}{\alpha}$ (b) $\frac{\alpha}{1+\alpha}$
(c) $\frac{\alpha}{1-\alpha}$ (d) $\alpha - \frac{1}{\alpha}$

Ans. *(c)*

Current gain in common-base configuration is,

$$\alpha = \left(\frac{\Delta i_c}{\Delta i_e}\right)_{V_{cb}} \quad \left[\begin{array}{l}\text{at constant voltage across}\\ \text{collector base junction}\end{array}\right]$$

Current gain in common-emitter configuration is,

$$\beta = \left(\frac{\Delta i_c}{\Delta i_b}\right)_{V_{ce}} \quad \left[\begin{array}{l}\text{at constant voltage across}\\ \text{collector emitter junction}\end{array}\right]$$

Also $\quad i_b = i_e - i_c$

or $\quad \Delta i_b = \Delta i_e - \Delta i_c$

As $\quad \beta = \frac{\Delta i_c}{\Delta i_b} = \frac{\Delta i_c}{\Delta i_e} \times \frac{\Delta i_e}{\Delta i_b}$

or $\quad \beta = \alpha \times \frac{\Delta i_e}{\Delta i_e - \Delta i_c}$

or $\quad \beta = \alpha \times \frac{1}{1 - \frac{\Delta i_c}{\Delta i_e}}$ or $\beta = \frac{\alpha}{1-\alpha}$

Altrernative As we know that relation between current gain in common base and common emitter configuration is given by

$$\alpha = \frac{\beta}{1+\beta}$$

$$\Rightarrow \quad \alpha + \alpha\beta = \beta \Rightarrow \beta - \alpha\beta = \alpha$$

$$\Rightarrow \quad \beta(1-\alpha) = \alpha$$

$$\Rightarrow \quad \beta = \frac{\alpha}{1-\alpha}$$

β is always greater than α. Also $\alpha < 1$ and $\beta > 1$..

88 The transfer ratio β of a transistor is 50. The input resistance of the transistor when used in the common emitter configuration is $1\,k\Omega$. The peak value of the collector AC current for an AC input voltage of 0.01 V peak is **[CBSE AIPMT 1998]**

(a) 100 μA (b) 0.01 mA
(c) 0.25 mA (d) 500 μA

Ans. *(d)*

Input current or base current is given by

$$i_b = \frac{\Delta V_b}{R_b} = \frac{0.01}{1000} = 10^{-5}\ \text{A} \quad \left[\begin{array}{l}\Delta V_b = \text{input voltage}\\ R_b = \text{base resistance}\end{array}\right]$$

Also current gain

$$\beta = \frac{i_c}{i_b}$$

$$\therefore \quad i_c = \beta i_b = 50 \times 10^{-5}\ \text{A} = 500 \times 10^{-6}\ \text{A} = 500\,\mu\text{A}$$

89 The correct relationship between the two current gains α and β in a transistor is **[CBSE AIPMT 1997]**

(a) $\beta = \frac{1+\alpha}{\beta}$ (b) $\alpha = \frac{\beta}{1+\beta}$
(c) $\alpha = \frac{\beta}{1-\beta}$ (d) $\beta = \frac{\alpha}{1+\alpha}$

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Ans. *(b)*

Current gain in common base configuration

$$\alpha = \frac{\Delta i_c}{\Delta i_e}$$

Current gain in common emitter configuration

$$\beta = \frac{\Delta i_c}{\Delta i_b}$$

And as we know that emitter current is equal to sum of base current and collector current

So, $i_e = i_b + i_c \Rightarrow \Delta i_e = \Delta i_b + \Delta i_c$

$$\therefore \quad \alpha = \frac{\Delta i_c}{\Delta i_b + \Delta i_c}$$

$$= \frac{\Delta i_c / \Delta i_b}{1 + \frac{\Delta i_c}{\Delta i_b}} = \frac{\beta}{1+\beta}$$

or $$\alpha = \frac{\beta}{\beta + 1}$$

90 The current gain for a transistor working as common base amplifier is 0.96. If the emitter current is 7.2 mA, then the base current is **[CBSE AIPMT 1996]**

(a) 0.29 mA (b) 0.35 mA
(c) 0.39 mA (d) 0.43 mA

Ans. *(a)*

DC current gain in common base amplifier is given by

$$\alpha = \frac{i_c}{i_e}$$

where, i_c is collector current and i_e is emitter current.

Given, $\alpha = 0.96, i_e = 7.2$ mA

$\therefore \quad i_c = 0.96 \times 7.2$ mA $= 6.91$ mA

As, $i_e = i_b + i_c$

$\therefore$ Base current $i_b = i_e - i_c$

$= 7.2 - 6.91 = 0.29$ mA

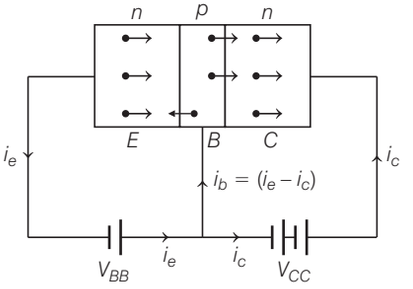
91 When a *n-p-n* transistor is used as an amplifier, then **[CBSE AIPMT 1996]**

(a) the electrons flow from emitter to collector
(b) the holes flow from emitter to collector
(c) the electrons flow from collector to emitter
(d) the electrons flow from battery to emitter

Ans. *(a)*

In *n-p-n* transistor, electrons are majority carriers in emitter (*n*-type semiconductor) and are repelled towards base by negative potential of V_{BB} as emitter base junction is forward biased i_e. The base being thin and lightly doped (*p*-type semiconductor) has low number density of holes.

When electrons enter the base region, then only a few holes (say 5%) get neutralised by the electron-hole combination, resulting base current ($i_b = 5\% \, i_e = 0.05 \, i_e$). The remaining 95% electrons pass over to the collector, on account of high positive potential of collector due to battery V_{CC}, resulting collector current ($i_c = 95\% \, i_e = 0.95 i_e$)



92 An oscillator is nothing but an amplifier with **[CBSE AIPMT 1994]**

(a) positive feedback
(b) negative feedback
(c) large gain
(d) no feedback

Ans. *(a)*

A transistor amplifier with proper positive feedback can act as an oscillator, i.e. it can generate oscillations without any external signal source. A positive feedback amplifier is one that produces a feedback voltage (V_f) that is in phase with the original input signal. A phase shift of 180° is produced by the amplifier and a further phase shift of 180° is introduced by feedback network. Consequently, the signal is shifted by 360° and fed to the input, i.e. feedback voltage is in phase with the input signal.

93 The part of the transistor which is heavily doped to produce large number of majority carriers is **[CBSE AIPMT 1993]**

(a) emitter
(b) base
(c) collector
(d) Any of the above depending upon the nature of transistor

Ans. *(a)*

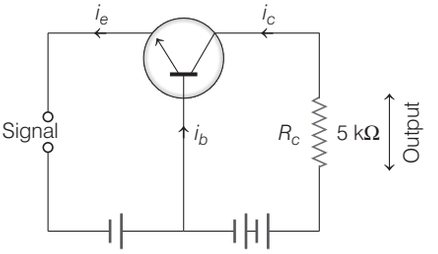
In transistor the emitter is heavily doped, so that it can inject a large number of charge carriers (electrons or holes) into the base. The base is lightly doped and very thin; it passes most of the emitter injected charge carriers to the collector. The collector is moderately doped.

94 To use a transistor as an amplifier **[CBSE AIPMT 1991]**

(a) the emitter base junction is forward biased and the base collector junction is reversed biased
(b) no bias voltage is required
(c) both junctions are forward biased
(d) both junctions are reverse biased

Ans. *(a)*

A transistor raises the strength of a weak signal and thus acts as an amplifier. In order to achieve faithful amplification, the input circuit should always remain forward biased. To do so, a DC voltage is applied in the input circuit in addition to the signal. This DC voltage is known as bias voltage and its magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal.



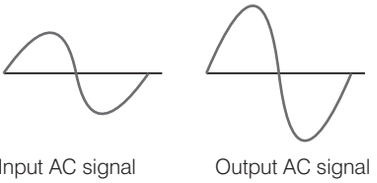
The collector-base junction is reverse biased and has a very high resistance of the order of mega ohms.

95 In a common base amplifier the phase difference between the input signal voltage and the output voltage is **[CBSE AIPMT 1990]**

(a) zero (b) $\frac{\pi}{4}$ (c) $\frac{\pi}{2}$ (d) π

Ans. *(a)*

In common base amplifier circuit, the input signal voltage and the output collector voltage are in the same phase.



Input AC signal Output AC signal

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96 Radiowaves of constant amplitude can be generated with **[CBSE AIPMT 1989]**

(a) FET (b) filter
(c) rectifier (d) oscillator

Ans. *(d)*

Many electronic devices require a source of energy at a specific frequency which may range from a few Hz to several MHz. This is achieved by an electronic device called an oscillator. An oscillator can produce waves from small (20 Hz) to extremely high frequencies (> 100 MHz).

TOPIC 3
Digital Circuits

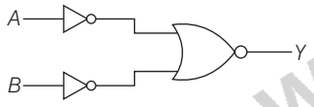
97 Which of the following gate is called universal gate? **[NEET (Oct.) 2020]**

(a) OR gate
(b) AND gate
(c) NAND gate
(d) NOT gate

Ans. *(c)*

NAND and NOR gate are called universal gate because all type of logic gates and Boolean expressions can be realised with the help of NAND and NOR gate.

98 For the logic circuit shown, the truth table is **[NEET (Sep.) 2020]**



(a)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

(b)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(c)

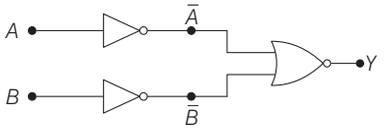
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(d)

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Ans. *(d)*

Given, logic circuit is



$$Y = \overline{\bar{A} + \bar{B}}$$
$$= \bar{\bar{A}} \cdot \bar{\bar{B}}$$

[using de-Morgan's theorem, $\overline{x + y} = \bar{x} \cdot \bar{y}$]

$$= A \cdot B \qquad [\because \bar{\bar{x}} = x]$$

Truth table for above given logic circuit is

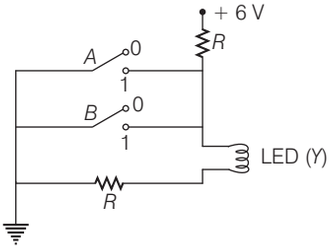
A	B	$\bar{A}$	$\bar{B}$	$Y = A \cdot B$
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

$\Rightarrow$

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Hence, correct option is (d).

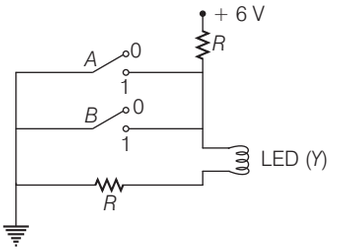
99 The circuit diagram shown here corresponds to the logic gate, **[NEET (Odisha) 2019]**



(a) NOR (b) AND (c) OR (d) NAND

Ans. *(a)*

From the circuit diagram given below, it can be seen that the current will flow to ground if any of the switch is closed. Also, the LED will only glow when current flows through it.

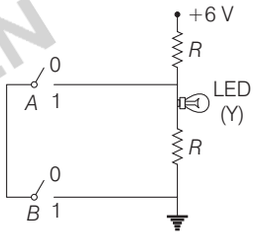


Thus, the truth table for the circuit diagram can be formed as circuit diagram in given solution.

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

The output (Y) is equivalent to that of NOR gate.

100

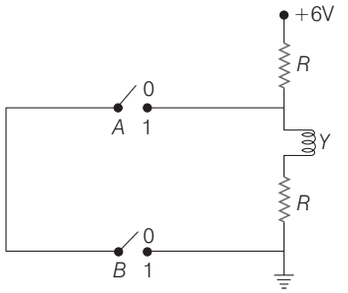


The correct Boolean operation represented by the circuit diagram drawn is **[NEET (National) 2019]**

(a) OR (b) NAND (c) NOR (d) AND

Ans. *(b)*

The LED will glow when the current flows through it, i.e. when the voltage across it is high. The truth table can be formed from this



A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

The output Y is same as that come from NAND gate.

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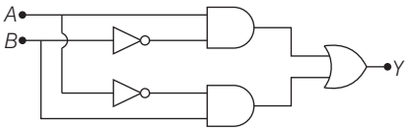
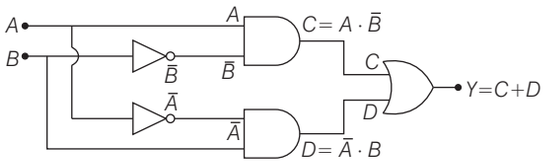
101 In the combination of the following gates the output Y can be written in terms of inputs A and B as **[NEET 2018]**



(a) $\overline{A \cdot B} + A \cdot B$ (b) $A \cdot \overline{B} + \overline{A} \cdot B$
(c) $\overline{A \cdot B}$ (d) $\overline{A + B}$

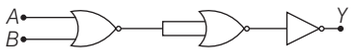
Ans. *(b)*

According to the question, the figure of combination of gates in terms of inputs and outputs can be given as



Thus, $Y = A \cdot \overline{B} + \overline{A} \cdot B$

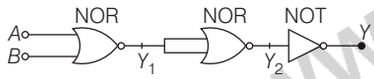
102 The given electrical network is equivalent to **[NEET 2017]**



(a) AND gate (b) OR gate
(c) NOR gate (d) NOT gate

Ans. *(c)*

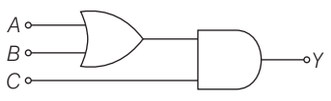
Truth table for given network is



A	B	Y_1	Y_2	Y
0	0	1	0	1
1	0	0	1	0
0	1	0	1	0
1	1	0	1	0

Output Y of network matches with that of NOR gate.

103 To get output 1 for the following circuit, the correct choice for the input is **[NEET 2016]**



(a) $A = 1, B = 0, C = 0$ (b) $A = 1, B = 1, C = 0$
(c) $A = 1, B = 0, C = 1$ (d) $A = 0, B = 1, C = 0$

Ans. *(c)*

Consider the given figure,

The resultant boolean expression of the above logic circuit will be

$$Y = (A + B).C$$

Now, let us try with inputs A, B and C given in the options and lets see, which one of them will give output 1 at Y.

If $A = 0, B = 0, C = 0$

$\Rightarrow \quad Y = (0 + 0).0 \Rightarrow Y = 0$

If $A = 1, B = 1, C = 0$

$\Rightarrow \quad Y = (1 + 1).0$

$\Rightarrow \quad Y = 1.0 \Rightarrow Y = 0$

If $A = 1, B = 0, C = 1$

$\Rightarrow \quad Y = (1 + 0).1 \Rightarrow Y = 1.1 \Rightarrow Y = 1$

If $A = 0, B = 1, C = 0$

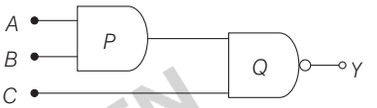
$\Rightarrow \quad Y = (0 + 1).0$

$\Rightarrow \quad Y = 1.0 \Rightarrow Y = 0$

So, we have seen that among the given options, only option (c) is the correct choice, i.e.

Output $Y = 1$ only when inputs $A = 1$, $B = 0$ and $C = 1$.

104 What is the output Y in the following circuit, when all the three inputs A, B, C are first 0 and then 1? **[NEET 2016]**



(a) 0, 1 (b) 0, 0
(c) 1, 0 (d) 1, 1

Ans. *(c)*

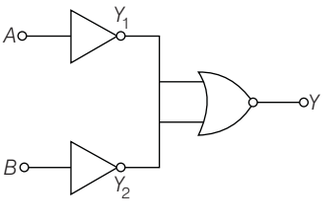
Output of the given circuit is given by

$$y = \overline{(AB)(C)}$$

When $A = B = C = 0$, $Y_1 = \overline{(0)(0)(0)} = \overline{0} = 1$

When $A = B = C = 1$, $Y_2 = \overline{(1)(1)} = 0$

105 Which logic gate is represented by the following combination of logic gates? **[CBSE AIPMT 2015]**



(a) OR (b) NAND (c) AND (d) NOR

Ans. *(c)*

The truth table for the given circuit is

A	B	y_1	y_2	$y = \overline{y_1 + y_2}$
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

The truth table shows that both the inputs are high, then we are getting high value of output otherwise zero. Hence, the combination represents AND gate.

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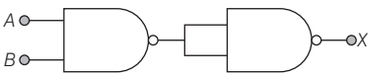
106 The output (X) of the logic circuit shown in figure will be **[NEET 2013]**



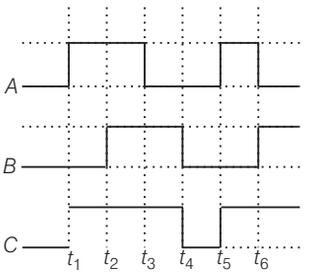
(a) $X = \overline{A} \cdot \overline{B}$ (b) $X = \overline{A \cdot B}$
(c) $X = A \cdot B$ (d) $X = \overline{A + B}$

Ans. *(c)*

(c) $X = \overline{\overline{AB}} = A \cdot B$ (i.e. AND gate)

If the output of NAND gate is connected to the input of NOT gate (made from NAND gate by joining two inputs) from the given figure then we get back an AND gate.

107 The figure shows a logic circuit with two inputs A and B and the output C. The voltage wave forms across A, B and C are as given. The logic circuit gate is **[CBSE AIPMT 2012]**



(a) OR gate (b) NOR gate
(c) AND gate (d) NAND gate

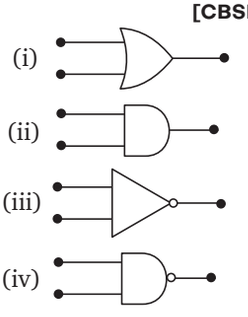
Ans. *(a)*

From the given waveforms, the following truth table can be made

Inputs		Output
A	*B*	*C*
0	0	0
1	0	1
1	1	1
0	1	1

This truth table obtained is of 'OR' gate. So, logic circuit gate is OR gate.

108 Symbolic representation of four logic gates are shown as **[CBSE AIPMT 2011]**



Pick out which ones are for AND, NAND and NOT gates, respectively.

(a) (iii), (ii) and (i) (b) (iii), (ii) and (iv)
(c) (ii), (iv) and (iii) (d) (ii), (iii) and (iv)

Ans. *(c)*

The symbols given in problem are
(i) OR (ii) AND (iii) NOT (iv) NAND

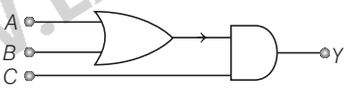
109 The device that can act as a complete electronic circuit is **[CBSE AIPMT 2010]**

(a) Junction diode
(b) Integrated circuit
(c) Junction transistor
(d) Zener diode

Ans. *(b)*

Integrated circuits are miniature electronic circuit produced within a single crystal of a semiconductor such as silicon. They contain a million or so transistors and resistors or capacitors. They are widely used in memory circuits, micro computers, pocket calculators and electronic watches on account of their low cost and bulk, reliability into specific regions of the semiconductor crystals.

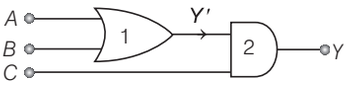
110 To get an output Y = 1 from the circuit shown below, the input must be **[CBSE AIPMT 2010]**



	A	B	C		A	B	C
(a)	0	1	0	(b)	0	0	1
(c)	1	0	1	(d)	1	0	0

Ans. *(c)*

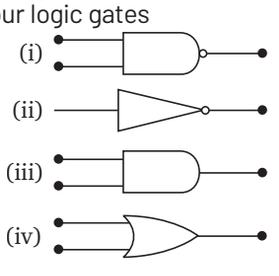
Gate I is OR gate, $Y' = A + B$



Gate II is AND gate, $Y = Y' \cdot C$

$\therefore$ $A = 1, B = 0, C = 1$ will give $Y = 1$

111 The symbolic representation of four logic gates



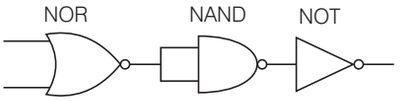
The logic symbols for OR, NOT and NAND gates are respectively **[CBSE AIPMT 2009]**

(a) (iii), (iv), (ii) (b) (iv), (i), (iii)
(c) (iv), (ii), (i) (d) (i), (iii), (iv)

Ans. *(c)*

The symbols given in problem are
(i) NAND (ii) NOT
(iii) AND (iv) OR

112 The circuit is equivalent to **[CBSE AIPMT 2008]**



(a) AND gate (b) NAND gate
(c) NOR gate (d) OR gate

Ans. *(c)*

The gate circuit can be solved by giving two inputs A and B.

Output of NOR gate, $Y_1 = \overline{A + B}$

Output of NAND gate, $Y_2 = \overline{Y_1 \cdot Y_1}$

$= \overline{\overline{A + B} \cdot \overline{A + B}}$

$= \overline{\overline{A + B}} + \overline{\overline{A + B}}$

$= A + B + A + B$

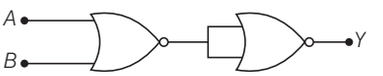
$= A + B$

Output of NOT gate,

$Y = \overline{Y}_2 = \overline{A + B}$

which is the output of NOR gate.

113 In the following circuit, the output Y for all possible inputs A and B is expressed by the truth table **[CBSE AIPMT 2007]**



(a)

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

(b)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(c)

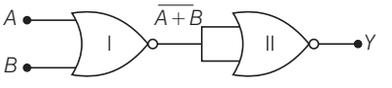
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(d)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Ans. *(d)*

We can simplify the gate circuit as



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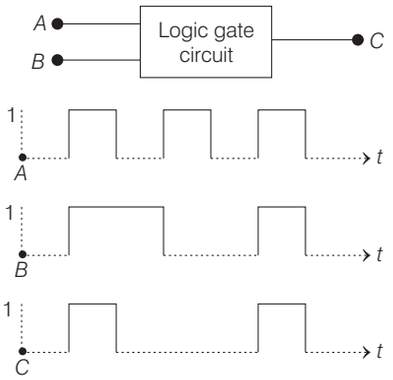
Here, gates-I and II are NOR gates. The output $(\overline{A+B})$ of gate-I will appear as input of gate-II. The final output is

$$Y = \overline{\overline{A+B}} = A + B$$

This is the Boolean expression of OR gate whose truth table is given below

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

114 The following figure shows a logic gate circuit with two inputs A and B and the output C. The voltage waveforms of A, B and C are as shown below



The logic circuit gate is

[CBSE AIPMT 2006]

(a) AND gate (b) NAND gate
(c) NOR gate (d) OR gate

Ans. *(a)*

The Boolean expression which satisfies the output of this logic gate is $C = A \cdot B$, which is for AND gate.

115 The output of OR gate is 1

[CBSE AIPMT 2004]

(a) only if both inputs are zero
(b) if either or both inputs are 1
(c) only if both inputs are 1
(d) if either input is zero

Ans. *(b)*

OR gate has two inputs A and B and output Y. It follows a logic operation represented by '+'. Thus, its Boolean expression is

$$A + B = Y$$

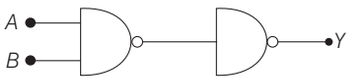
The truth table of OR gate is

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Thus, after observing its Boolean expression and its truth table, it is obvious that output of OR gate is 1 if either or both inputs are 1.

116 Following diagram performs the logic function of

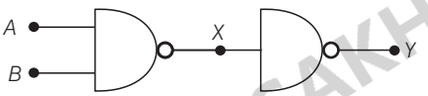
[CBSE AIPMT 2003]



(a) OR gate (b) AND gate
(c) XOR gate (d) NAND gate

Ans. *(b)*

For our convenience, the output of first NAND gate is chosen as X as shown



Output of first NAND gate, $X = \overline{A \cdot B}$

Using De-Morgan's theorem

$$\overline{A \cdot B} = \overline{A} + \overline{B}$$

So, $X = \overline{A} + \overline{B}$

Now, output of 2nd NAND gate,

$$Y = \overline{X} = \overline{\overline{A} + \overline{B}}$$

Again $\overline{\overline{A} + \overline{B}} = \overline{\overline{A}} \cdot \overline{\overline{B}} = A \cdot B$ $(\because \overline{\overline{A}} = A)$

Hence, $Y = A \cdot B$

This is the logic function of AND gate.

117 The truth table given below

Input		Output
A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1

represents **[CBSE AIPMT 2000]**

(a) AND gate (b) NOR gate
(c) OR gate (d) NAND gate

Ans. *(a)*

We can see from the truth table that output is 1 only when its both inputs are 1.

This is possible only for AND gate. The Boolean expression for AND gate is

$$Y = A \cdot B$$

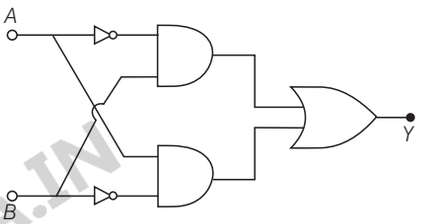
which satisfies the truth table as below

$$0 \cdot 0 = 0$$
$$1 \cdot 0 = 0$$
$$0 \cdot 1 = 0$$
$$1 \cdot 1 = 1$$

Here symbol (·) represents AND operation.

118 The following circuit represents

[CBSE AIPMT 1999]



(a) OR gate
(b) XOR gate
(c) AND gate
(d) NAND gate

Ans. *(b)*

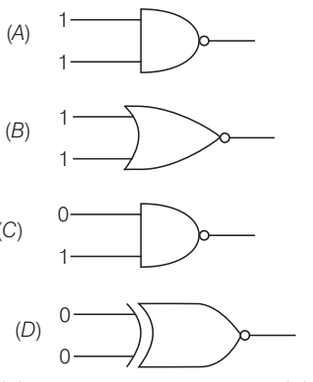
Output of upper AND gate $= \overline{A}B$

Output of lower AND gate $= A\overline{B}$

Thus, output of OR gate $= \overline{A}B + A\overline{B}$

This is Boolean expression for XOR gate.

119 Which one of the following gates will have an output of 1 ? **[CBSE AIPMT 1998]**



(a) A (b) B
(c) C (d) D

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Ans. *(c)*

(a) Gate A is NAND gate, its output will be

$$Y_A = \overline{1 \cdot 1} = \overline{1} = 0$$

(b) Gate B is NOR gate, its output will be

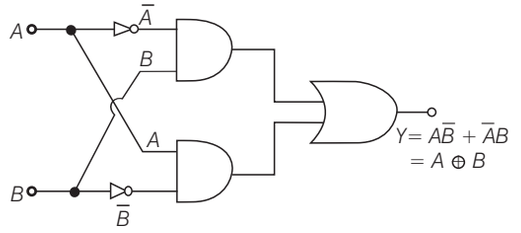
$$Y_B = \overline{1 + 1} = \overline{1} = 0$$

(c) Gate C is NAND gate, its output will be

$$Y_C = \overline{0 \cdot 1} = \overline{0} = 1$$

(d) Gate D is XOR gate, its output will be

$$Y_D = 0 \oplus 0 = 0 \cdot \overline{0} + \overline{0} \cdot 0 = 0$$



Thus, gate (C) will give an output of 1.

120 The following truth table belongs to which of the following four gates ? **[CBSE AIPMT 1997]**

Input		Output
A	*B*	*Y*
1	1	0
1	0	0
0	1	0
0	0	1

(a) NOR (b) XOR
(c) NAND (d) OR

Ans. *(a)*

The Boolean expression expressed by the truth table may be written as

$$Y = \overline{A + B}$$

This is the expression of NOR gate (OR gate + NOT gate)

NOTE

The NOR gate may be shown as below

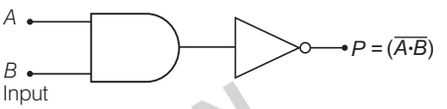
121 Which of the following gates corresponds to the truth table given below? **[CBSE AIPMT 1994]**

Input		Output
A	*B*	*Y*
1	1	0
1	0	1
0	1	1
0	0	1

(a) NAND (b) OR
(c) AND (d) XOR

Ans. *(a)*

Truth table for NAND gate is developed by inverting the outputs of the AND gate with NOT gate. Output from a NAND gate is always 1 except when all the inputs are 1. Diagrametic representation of NAND gate is



122 The following truth table corresponds to the logical gate **[CBSE AIPMT 1991]**

Input		Output
A	*B*	*Y*
0	0	0
0	1	1
1	0	1
1	1	1

(a) NAND (b) OR
(c) AND (d) XOR

Ans. *(b)*

It is clear from the truth table that the output is high if any or all of the inputs are high. The only way to get a low output is by having all inputs low. The output Y of an OR gate is low when all inputs are low. The output Y of an OR gate is high, if any or all the inputs are high. So this truth table is of OR gate.

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